Current Reactor Technology and Advanced Technology Development

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Contents

- Basics of Nuclear Power
- Evolution of Nuclear Technology
- Water Cooled Reactors
- Small and Medium Size Reactors
- Gas Cooled Reactors
- Fast Reactors
- Generation IV Reactors
- Non-electrical Applications

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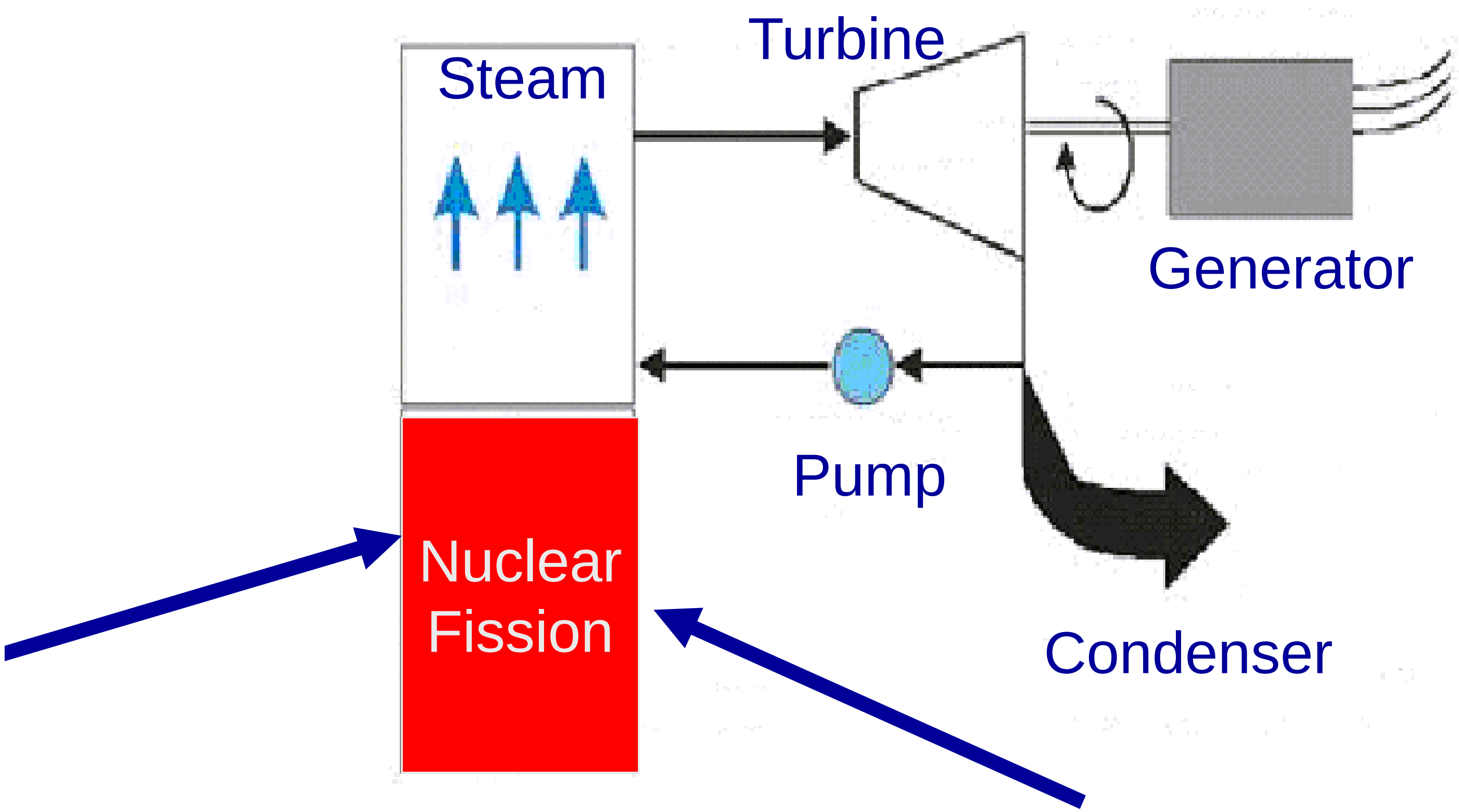
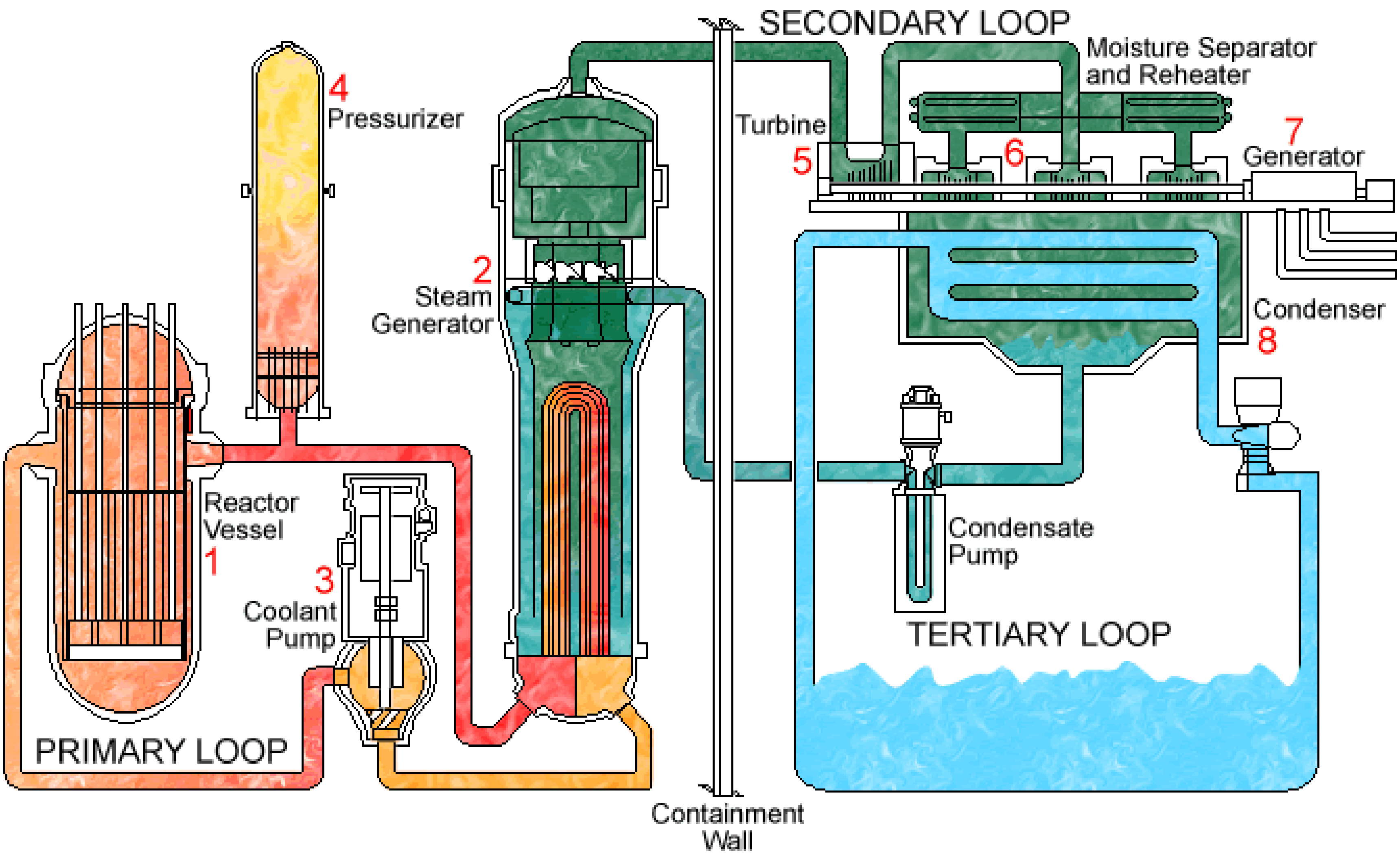
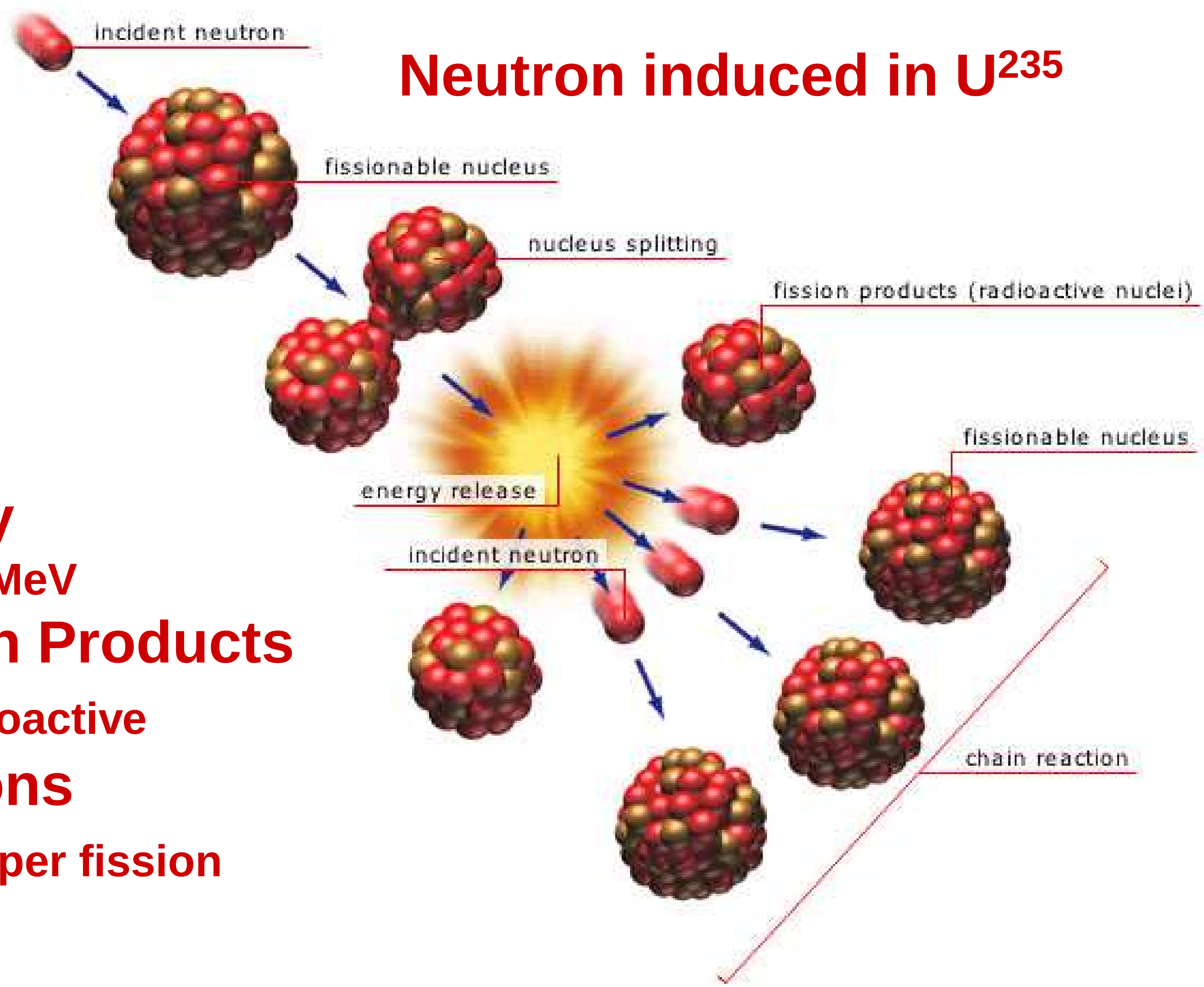
The Basic Power Plant



Typical Nuclear Power Plant



Nuclear Fission



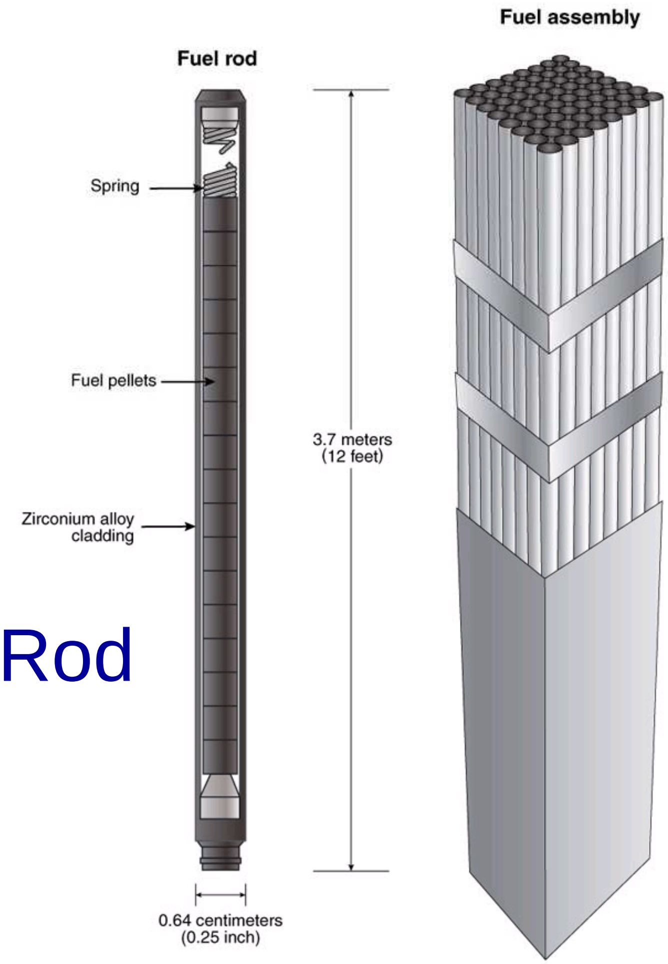
Neutron induced in U^{235}

Products:

- **Energy**
  - **~ 200 MeV**
- **Fission Products**
  - **Radioactive**
- **Neutrons**
  - **2.47 per fission**

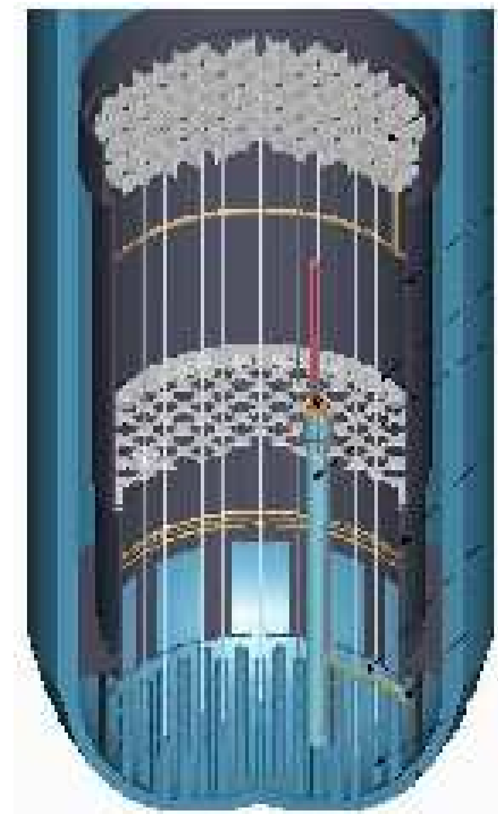
Typical Reactor Core

Fuel Pellet



Fuel Rod

Fuel Assembly



Reactor Core / Reactor Vessel

Nuclear has high energy density

The energy contained in one fuel pellet…

=

3.5 barrels of oil (165 gallons)

1 ton of coal

17,000 cubic feet of natural gas

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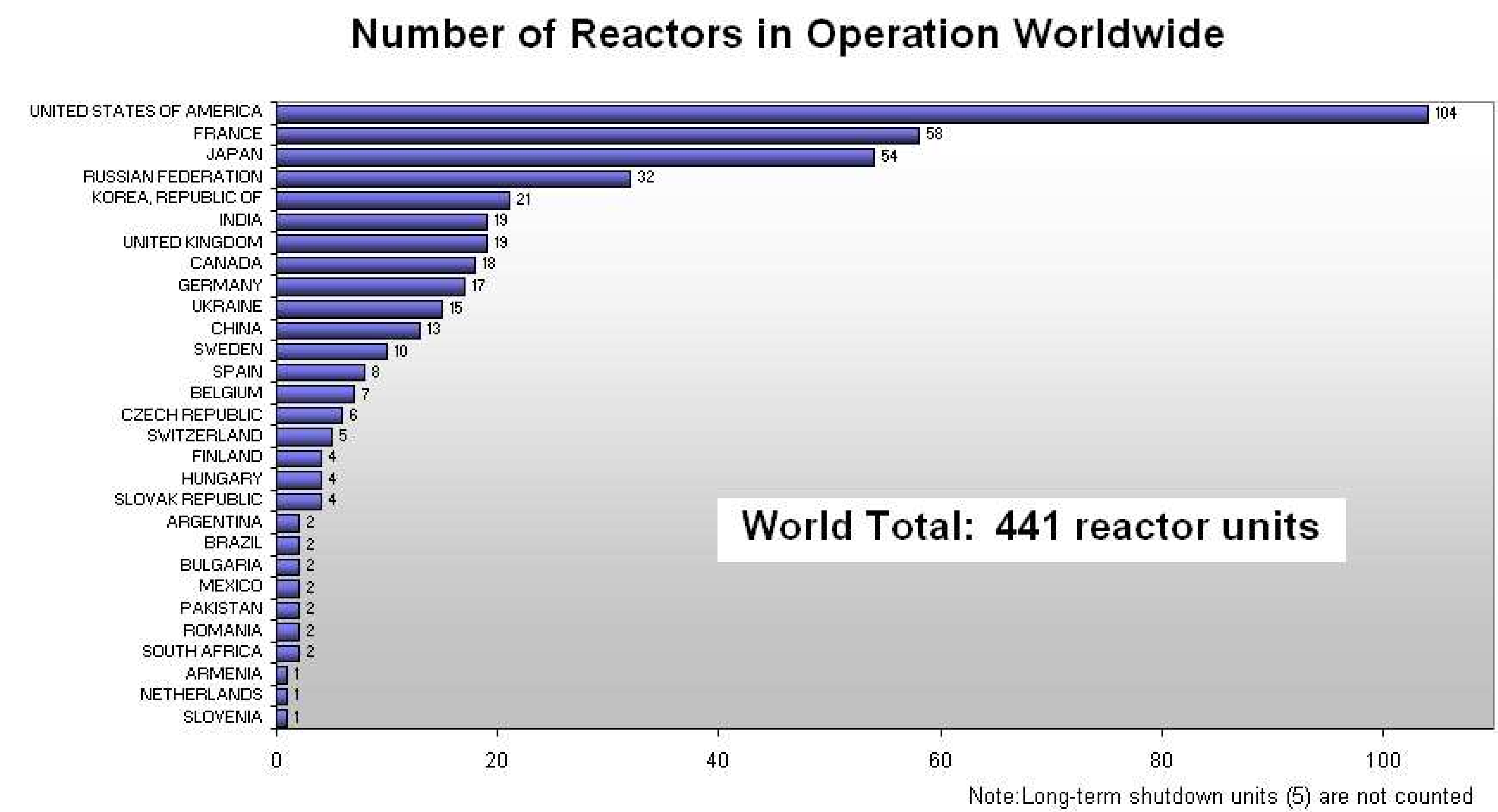
Reactors Currently in Operation



Source: PRIS, IAEA, 11/02/2010

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Types of Nuclear Reactors

- Water Cooled Reactors
  - Light Water Cooled (BWR, PWR)
  - Heavy Water (PHWR, CANDU type)
- Gas Cooled Reactors
  - CO_2 (GCR)
  - Helium (HTGR)
- Liquid Metal Cooled Reactors
  - Sodium
  - Lead or Lead-Bismuth

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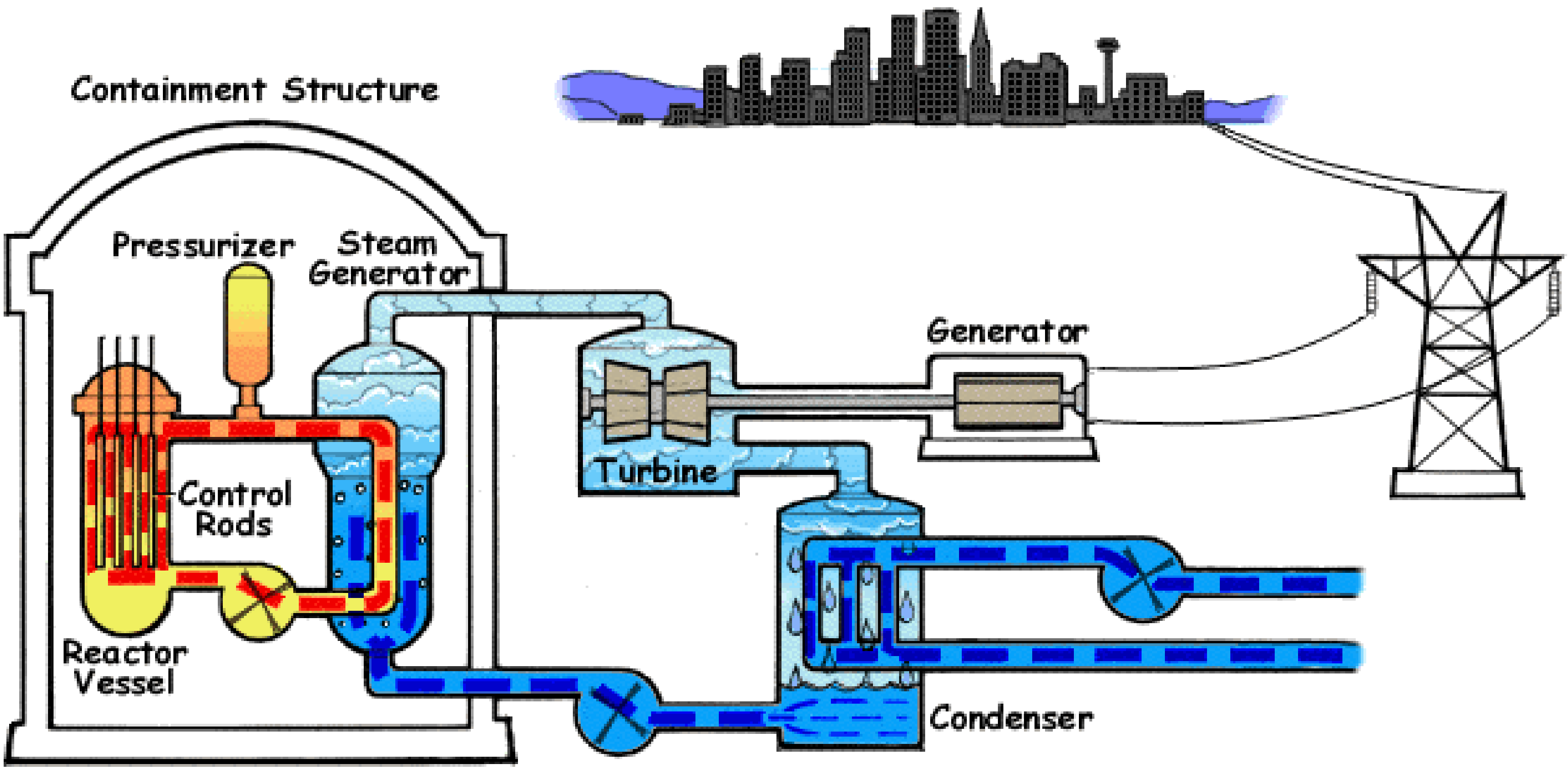
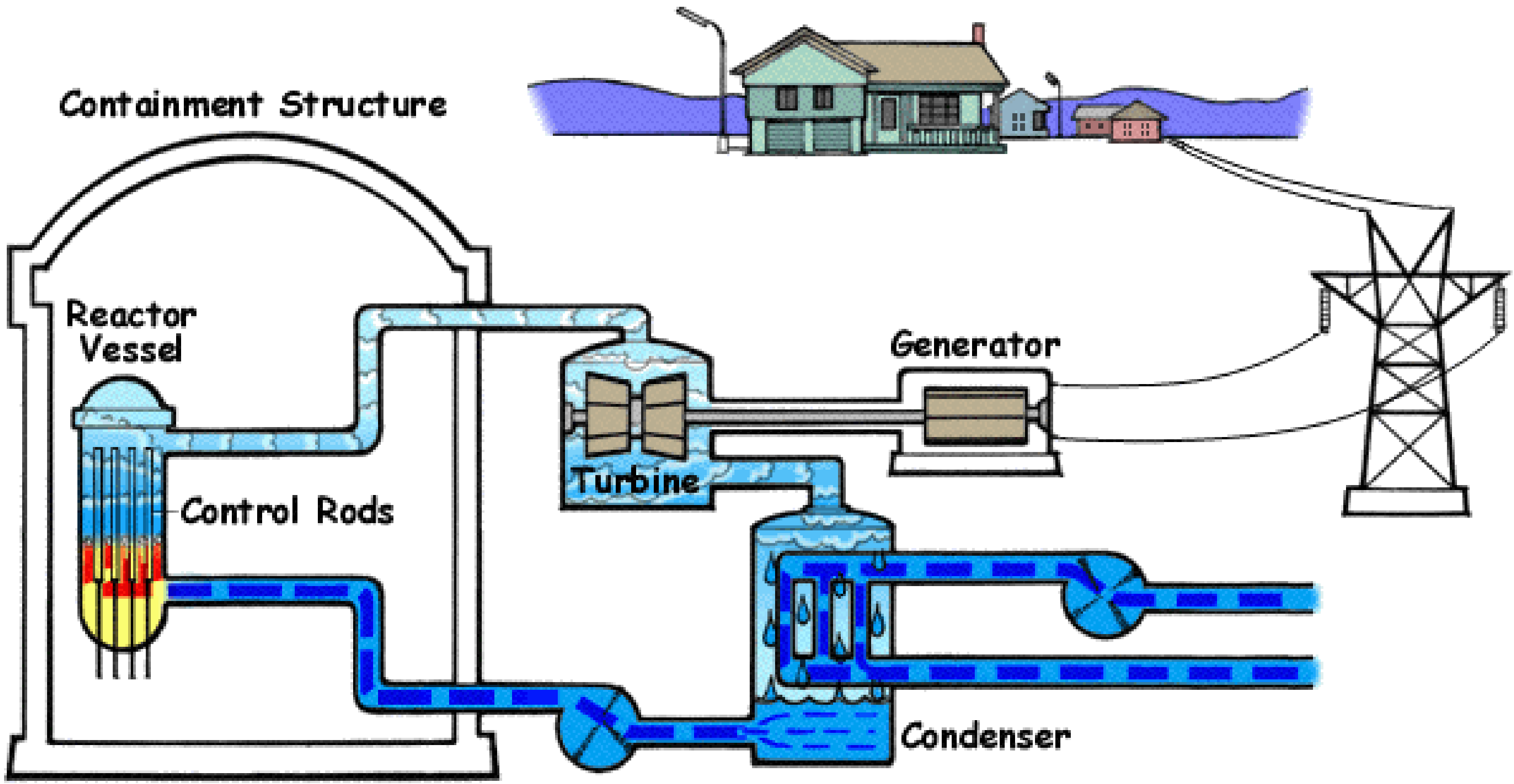
Pressurized Water Reactor (PWR)

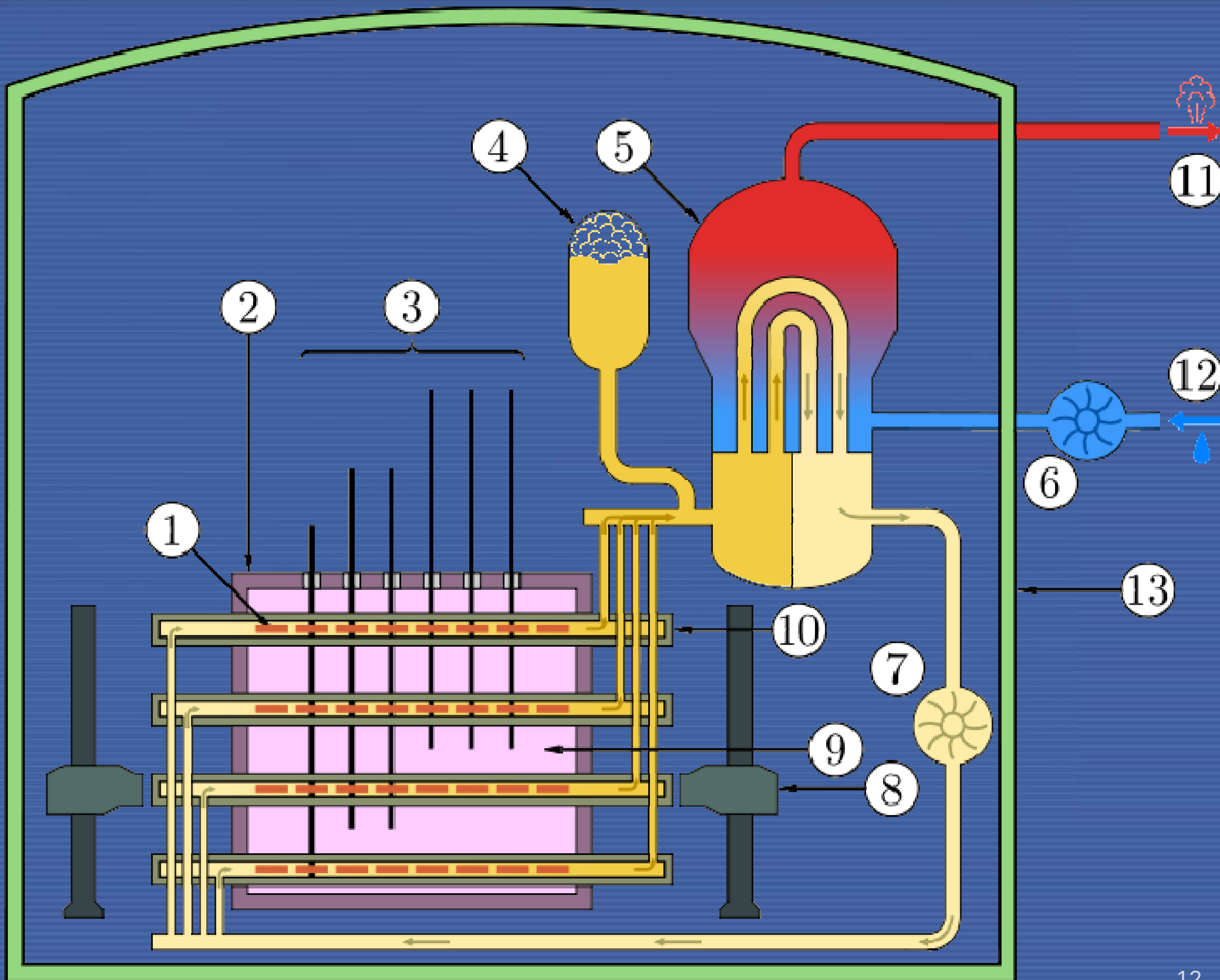


Boiling Water Reactor (BWR)



Pressurized Heavy Water Reactor (PHWR)

1. Nuclear Fuel Rod
2. Calandria
3. Control Rods
4. Pressurizer
5. Steam Generator
6. Light Water Condensate pump
7. Heavy Water Pump
8. Nuclear Fuel Loading Machine
9. Heavy Water Moderator
10. Pressure Tubes
11. Steam
12. Water Condensate
13. Containment



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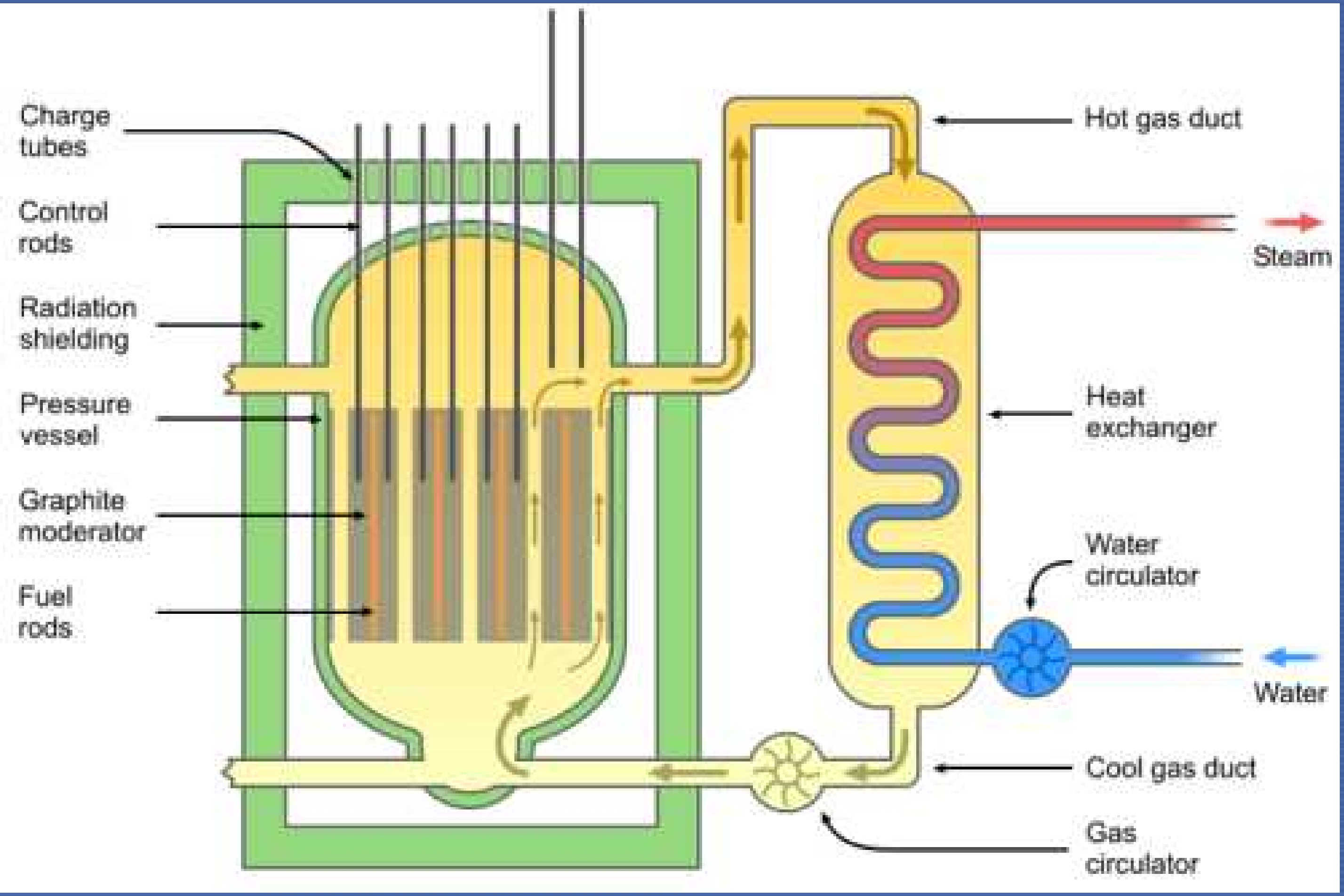
Gas Cooled Reactor



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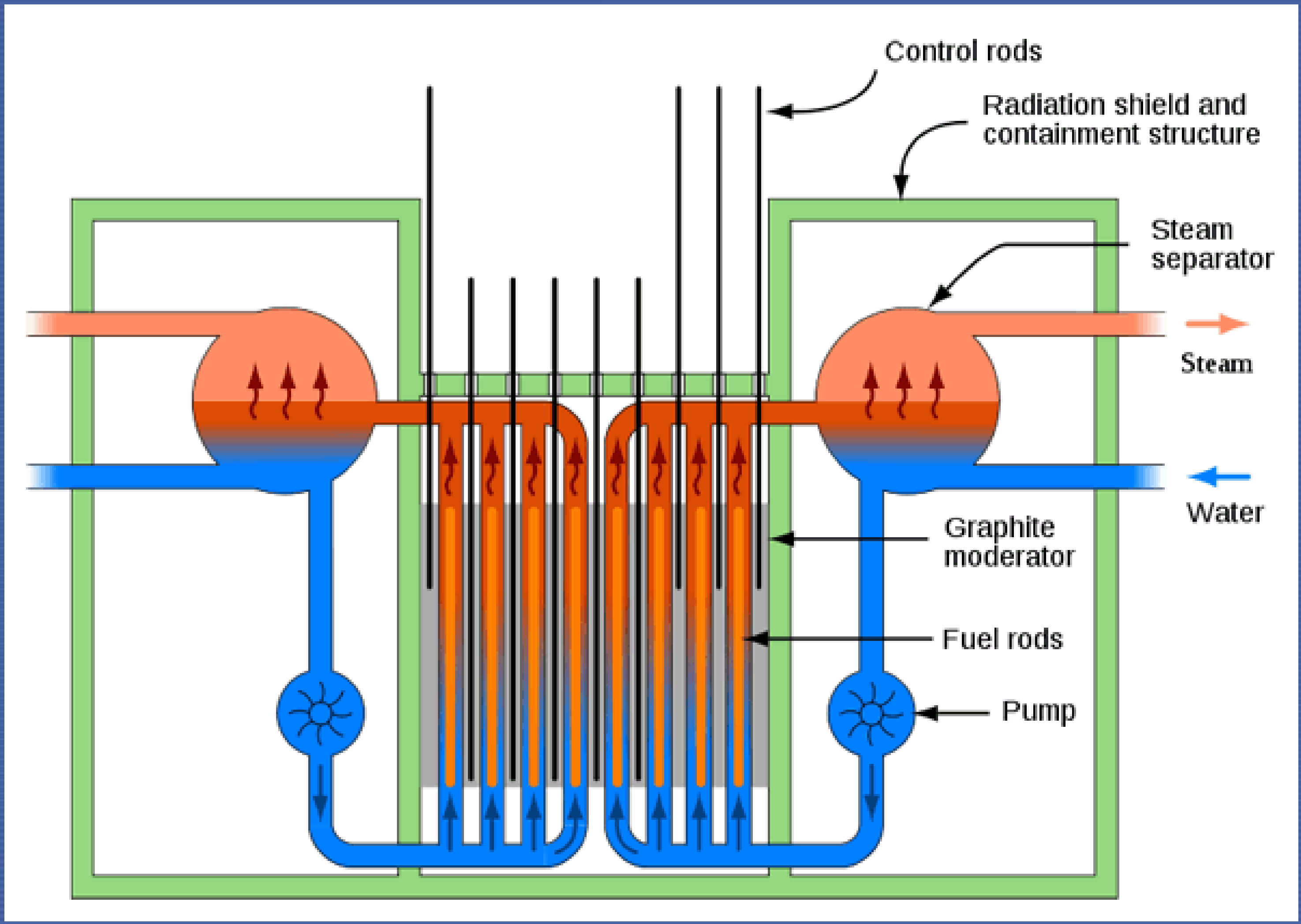
LWGR Type Reactor

LWGR = Light Water cooled Graphite moderated Reactor



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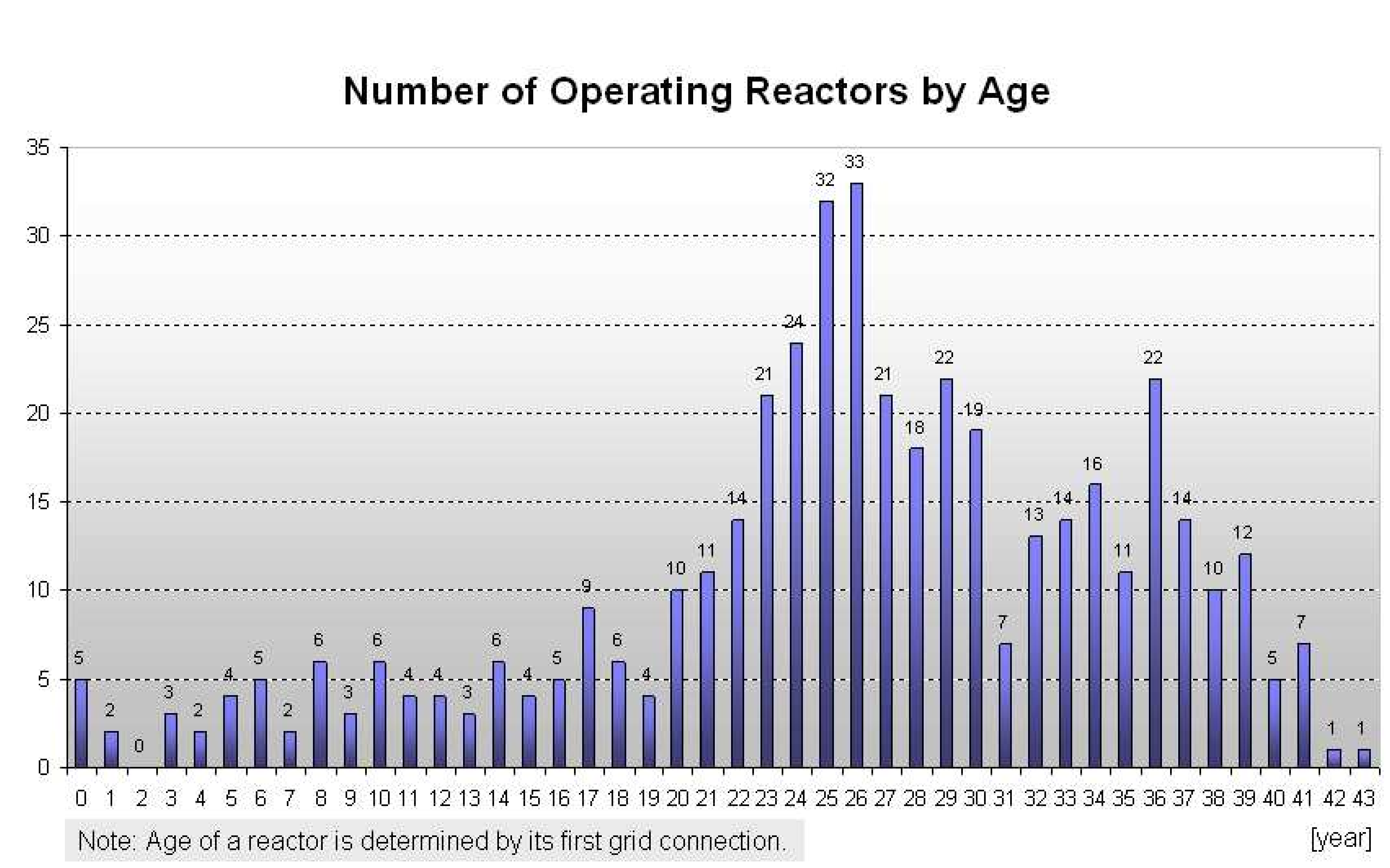
NPP in Operation by Age



Source: PRIS, IAEA, 11/02/2010

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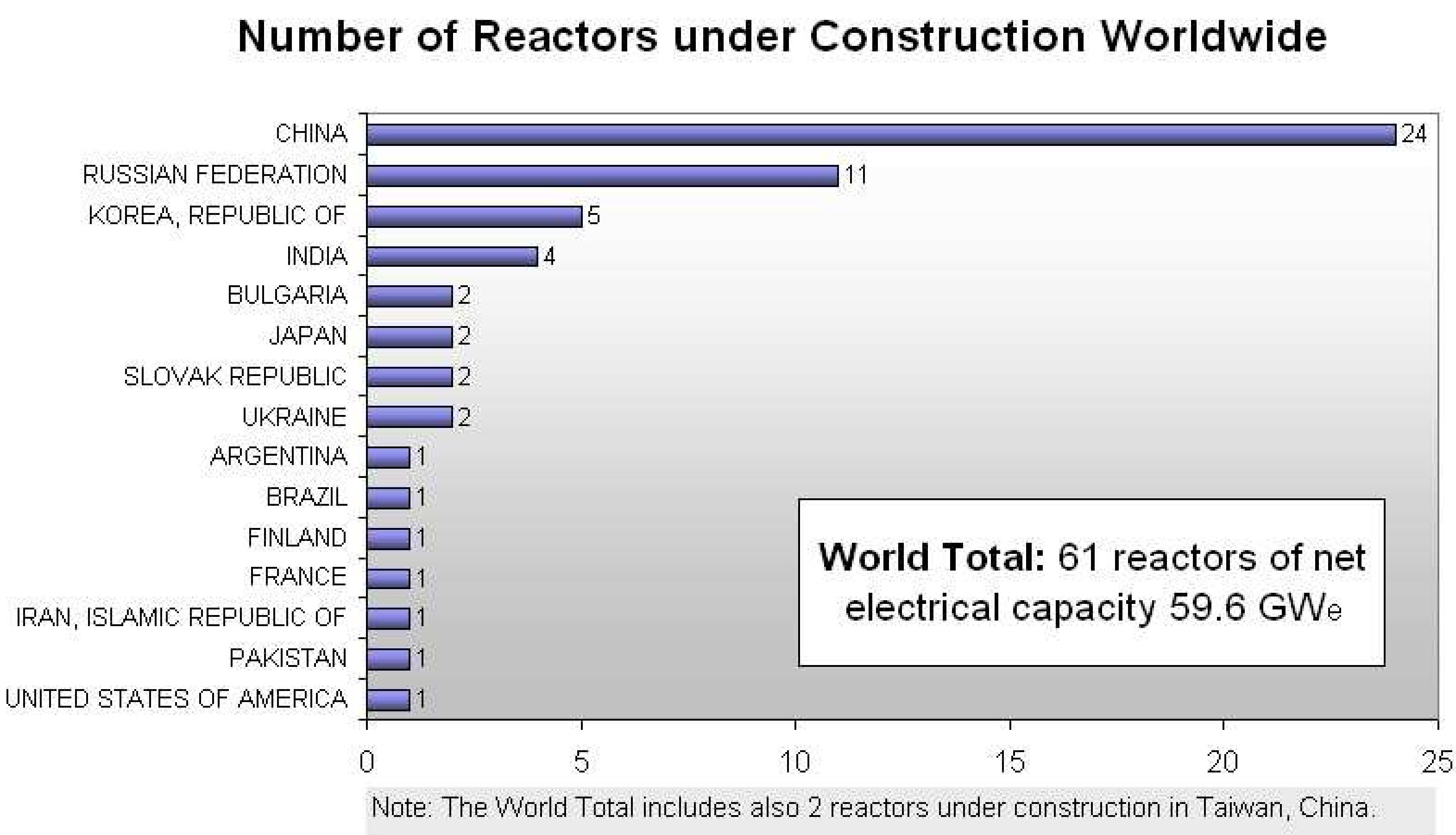
NPPs Under Construction



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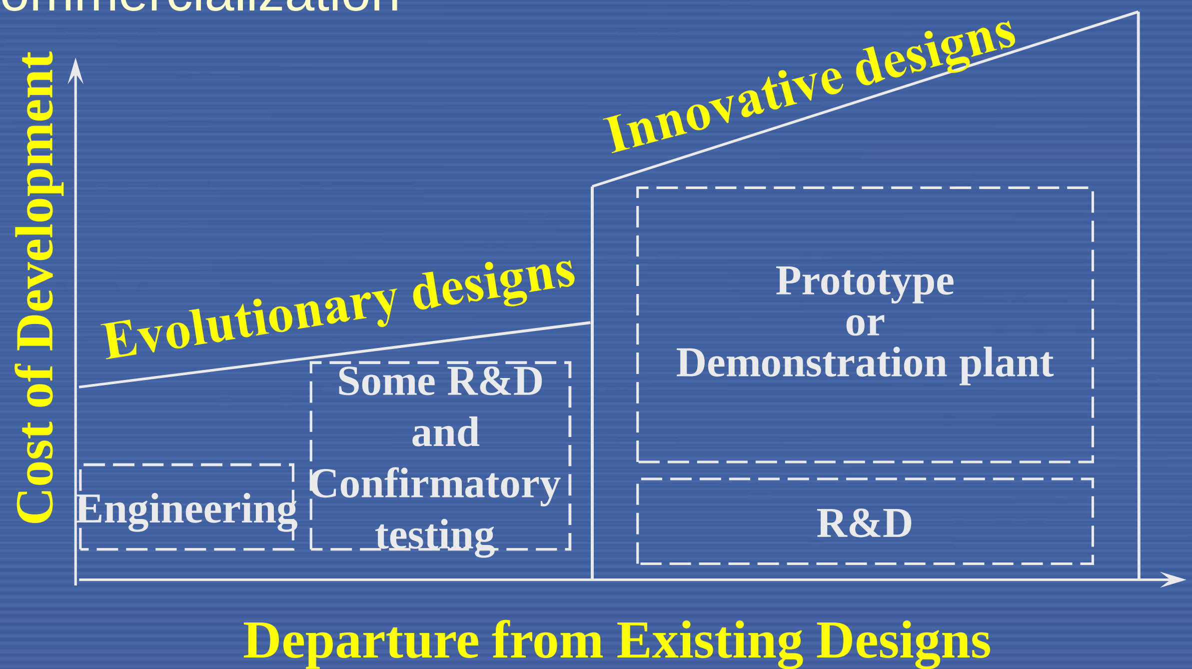
Source: PRIS, IAEA, 11/02/2010

Advanced Reactor Designs

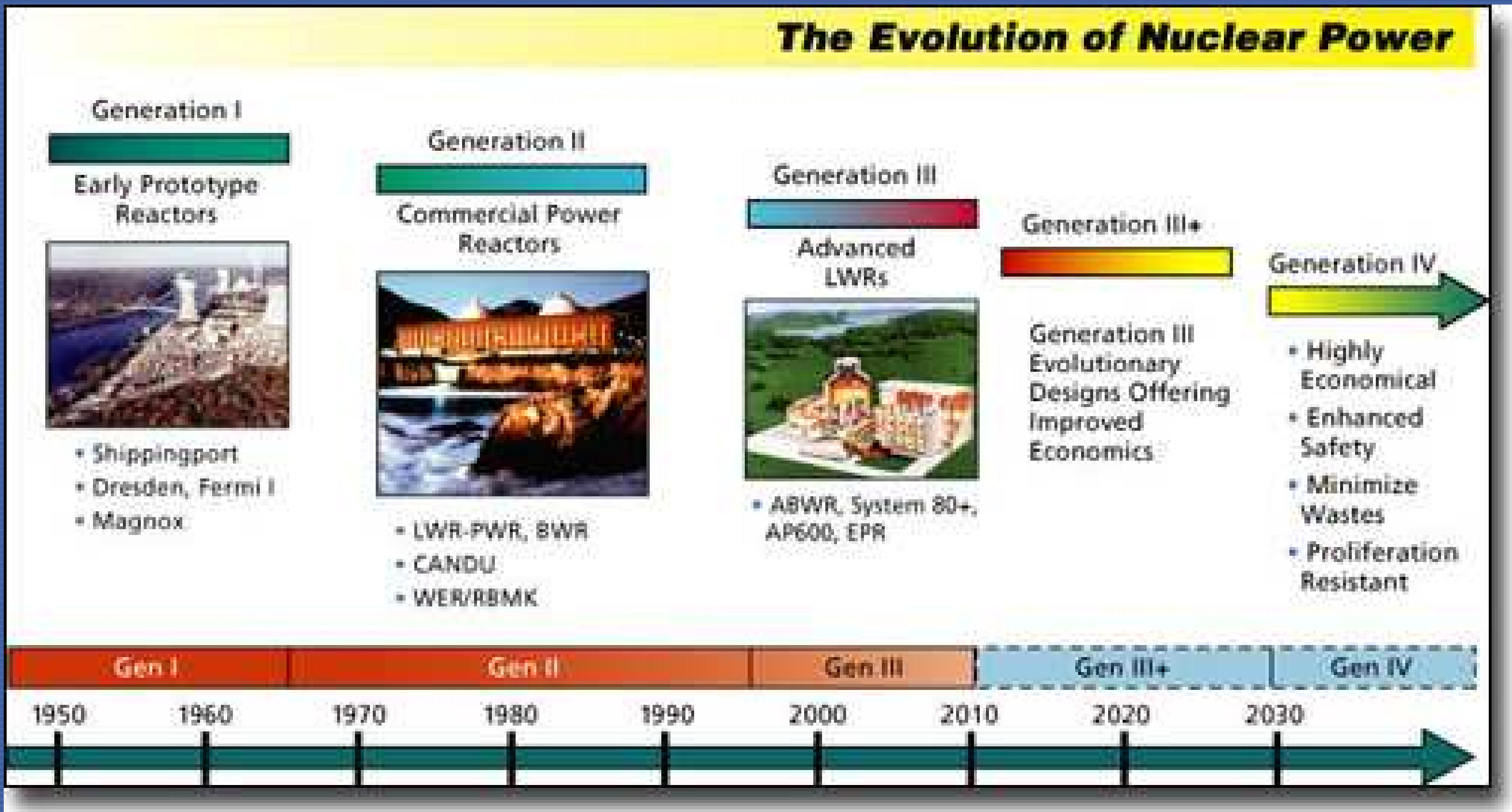
(defined in IAEA-TECDOC-936)

- **Evolutionary Designs** - achieve improvements over existing designs through small to moderate modifications

- **Innovative Designs** - incorporate radical conceptual changes and may require a prototype or demonstration plant before commercialization



Another classification…



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Evolutionary = Generation III & III+

- Current NPP → Generation II
- Advanced NPP
  - Evolutionary NPP → Generation III / Generation III+
  - Innovative NPP → Generation IV

Challenges in Nuclear Technology Deployment

- Economic competitiveness
- Countries' National nuclear energy strategy
- Nuclear industry infrastructure
- Effective regulation and licensing process
- Financing schemes and business cases
- Spent fuel and waste management
- Proliferation resistance and physical protection
- Public acceptance

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Global Trends in Advanced Reactor Design

- **Cost Reduction**
  - Standardization and series construction
  - Improving construction methods to shorten schedule
  - Modularization and factory fabrication
  - Design features for longer lifetime
  - Fuel cycle optimization
  - Economy of scale → larger reactors
  - Affordability → SMRs
- **Performance Improvement**
  - Establishment of user design requirements
  - Development of highly reliable components and systems, including "smart" components
  - Improving the technology base for reducing over-design
  - Further development of PSA methods and databases
  - Development of passive safety systems
  - Improved corrosion resistant materials
  - Development of Digital Instrumentation and Control
  - Development of computer based techniques
  - Development of systems with higher thermal efficiency and expanded applications (Non-electrical applications)

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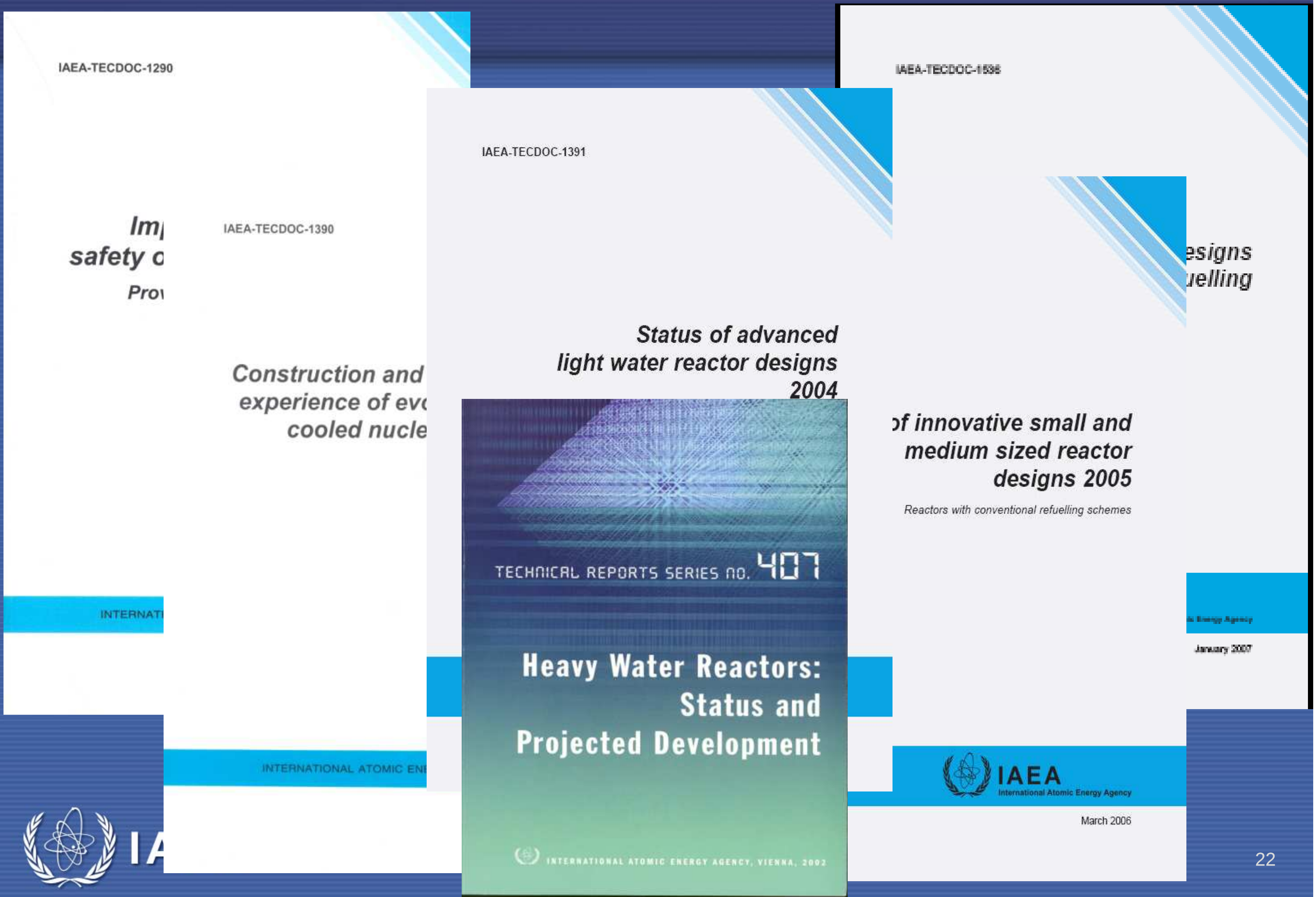
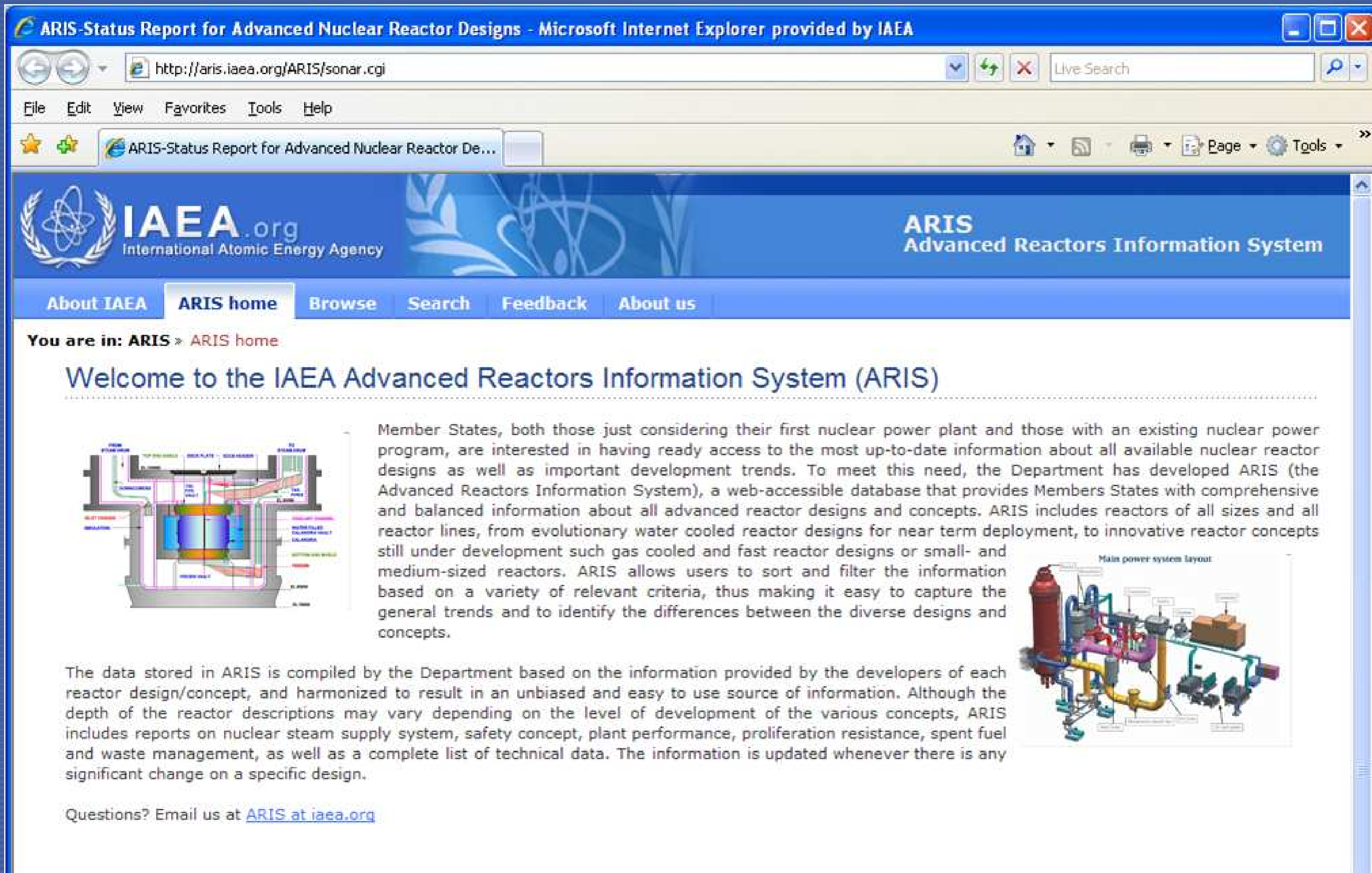
IAEA Publications on Advanced Reactors



http://aris.iaea.org/



ARIS-Status Report for Advanced Nuclear Reactor Designs - Microsoft Internet Explorer provided by IAEA

http://aris.iaea.org/ARIS/sonar.cgi

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ARIS Advanced Reactors Information System

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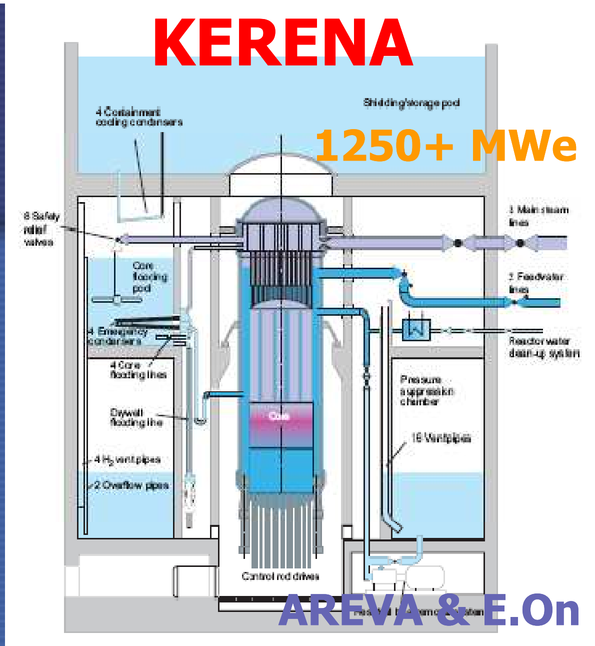
Welcome to the IAEA Advanced Reactors Information System (ARIS)

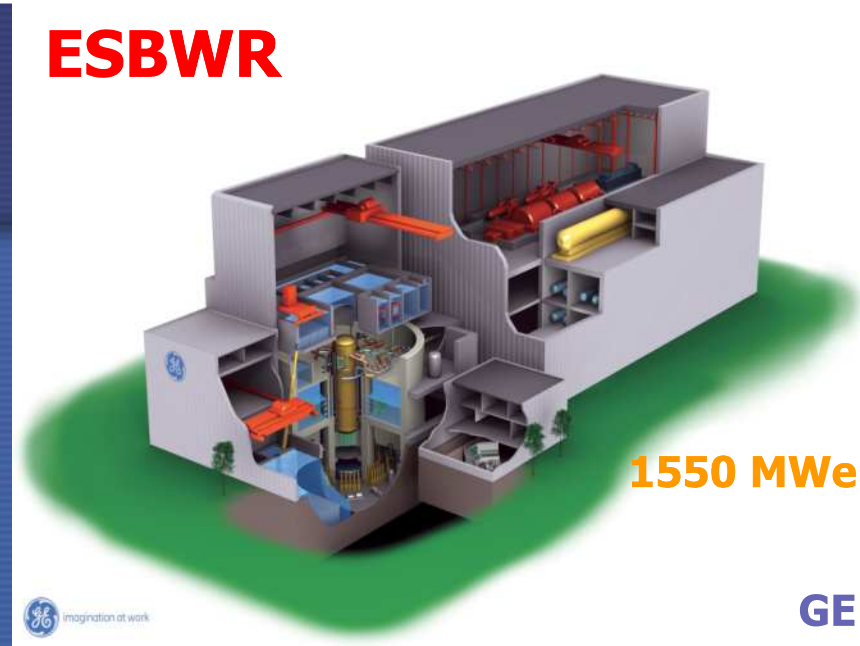
Member States, both those just considering their first nuclear power plant and those with an existing nuclear power program, are interested in having ready access to the most up-to-date information about all available nuclear reactor designs as well as important development trends. To meet this need, the Department has developed ARIS (the Advanced Reactors Information System), a web-accessible database that provides Members States with comprehensive and balanced information about all advanced reactor designs and concepts. ARIS includes reactors of all sizes and all reactor lines, from evolutionary water cooled reactor designs for near term deployment, to innovative reactor concepts still under development such gas cooled and fast reactor designs or small- and medium-sized reactors. ARIS allows users to sort and filter the information based on a variety of relevant criteria, thus making it easy to capture the general trends and to identify the differences between the diverse designs and concepts.

Main power system layout

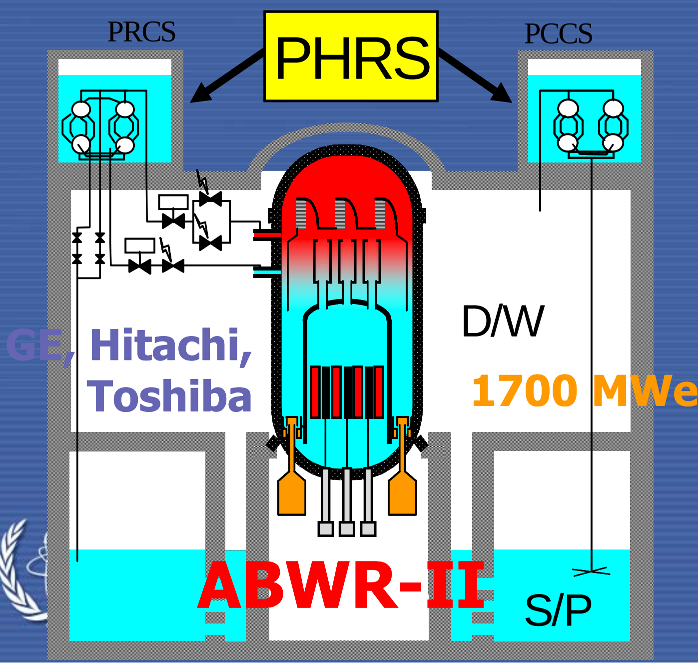
The data stored in ARIS is compiled by the Department based on the information provided by the developers of each reactor design/concept, and harmonized to result in an unbiased and easy to use source of information. Although the depth of the reactor descriptions may vary depending on the level of development of the various concepts, ARIS includes reports on nuclear steam supply system, safety concept, plant performance, proliferation resistance, spent fuel and waste management, as well as a complete list of technical data. The information is updated whenever there is any significant change on a specific design.

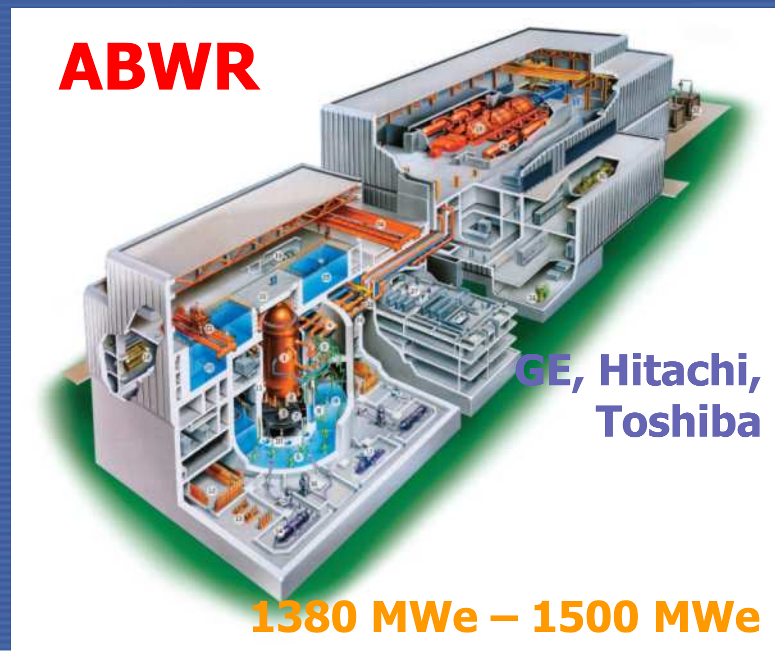
Questions? Email us at ARIS at iaea.org





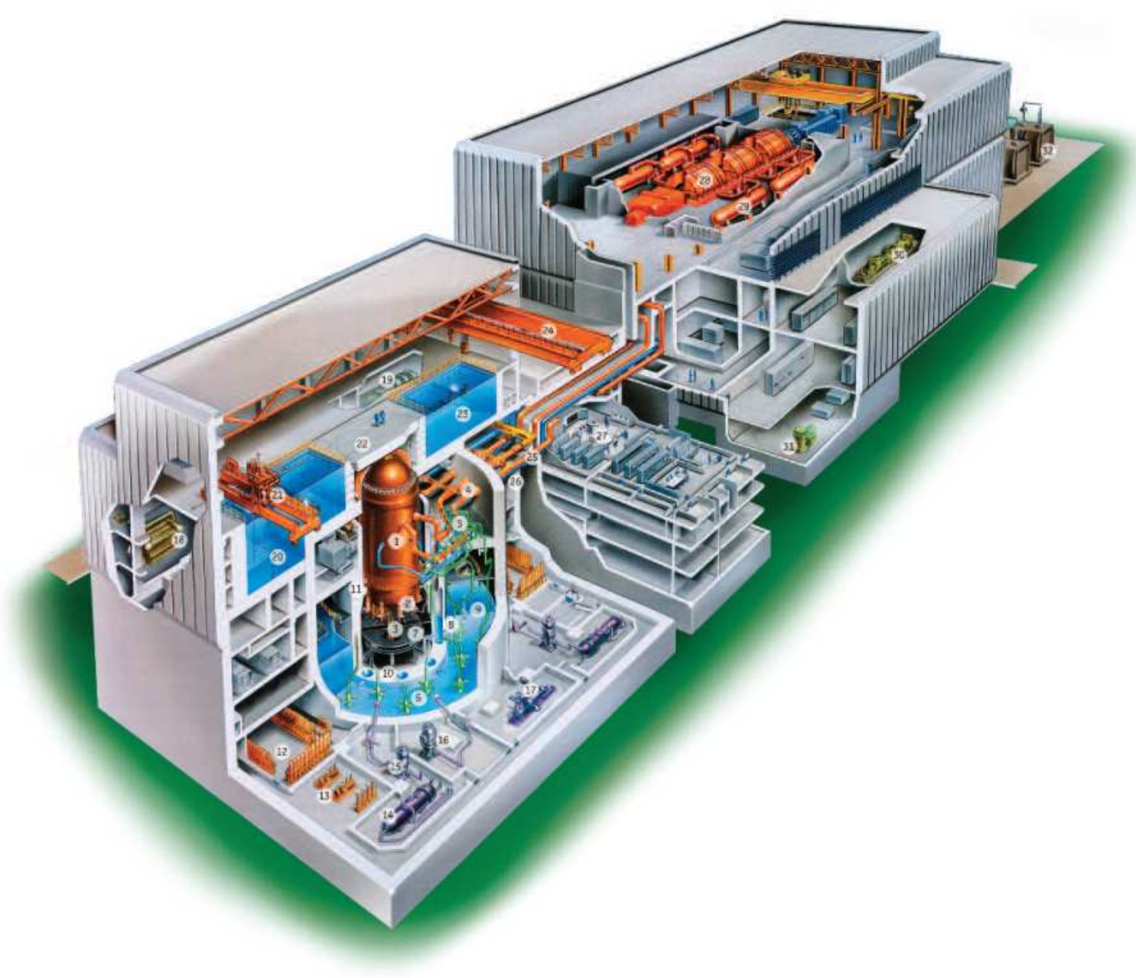
Boiling Water Reactors (BWR)





Advanced Boiling Water Reactor (ABWR)

- Originally by GE, then Hitachi & Toshiba
- Developed in response to URD
- First Gen III reactor to operate commercially
- Licensed in USA, Japan & Taiwan, China
- 1380 MWe - 1500 MWe
- Shorter construction time
- Standardized series
  - 4 in operation (Kashiwazaki-Kariwa -6 & 7, Hamaoka-5 and Shika-2)
  - 7 planned in Japan
  - 2 under construction in Taiwan, China
  - Proposed for South Texas Project (USA)



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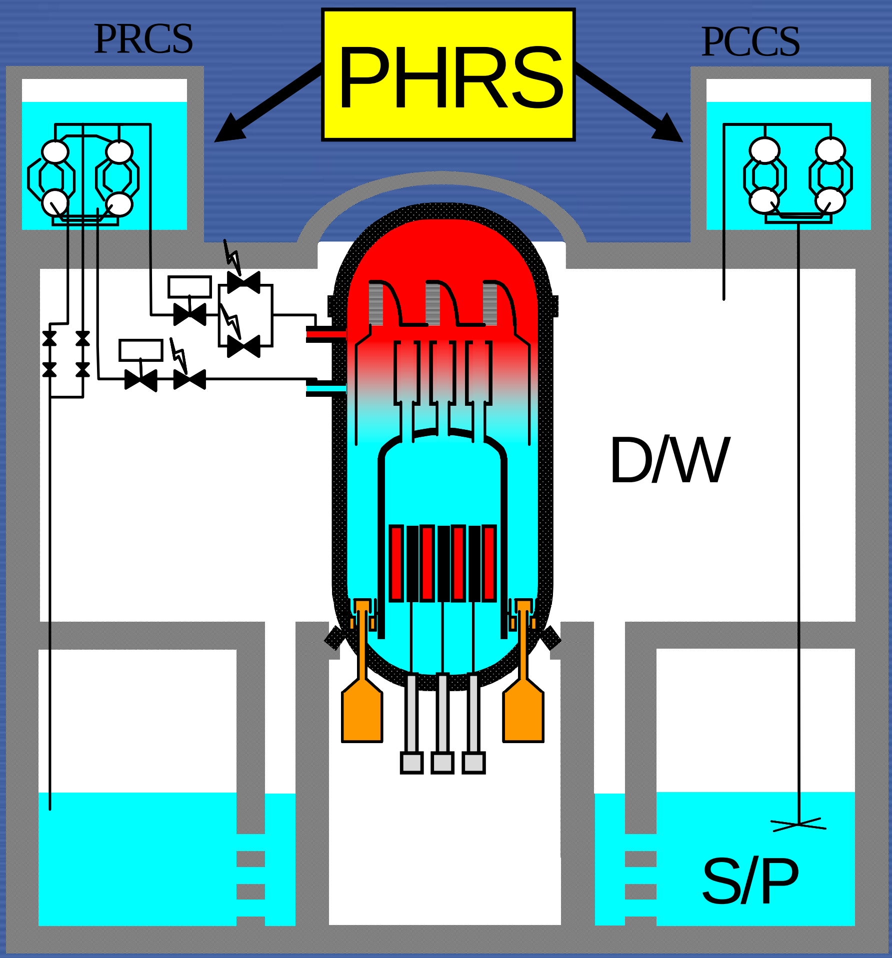
ABWR-II

- Early 1990s – TEPCO & 5 other utilities, GE, Hitachi and Toshiba began development
- 1700 MWe
- Goals
  - 30% capital cost reduction
  - reduced construction time
  - 20% power generation cost reduction
  - increased safety
  - increased flexibility for future fuel cycles
- Goal to Commercialize – latter 2010s



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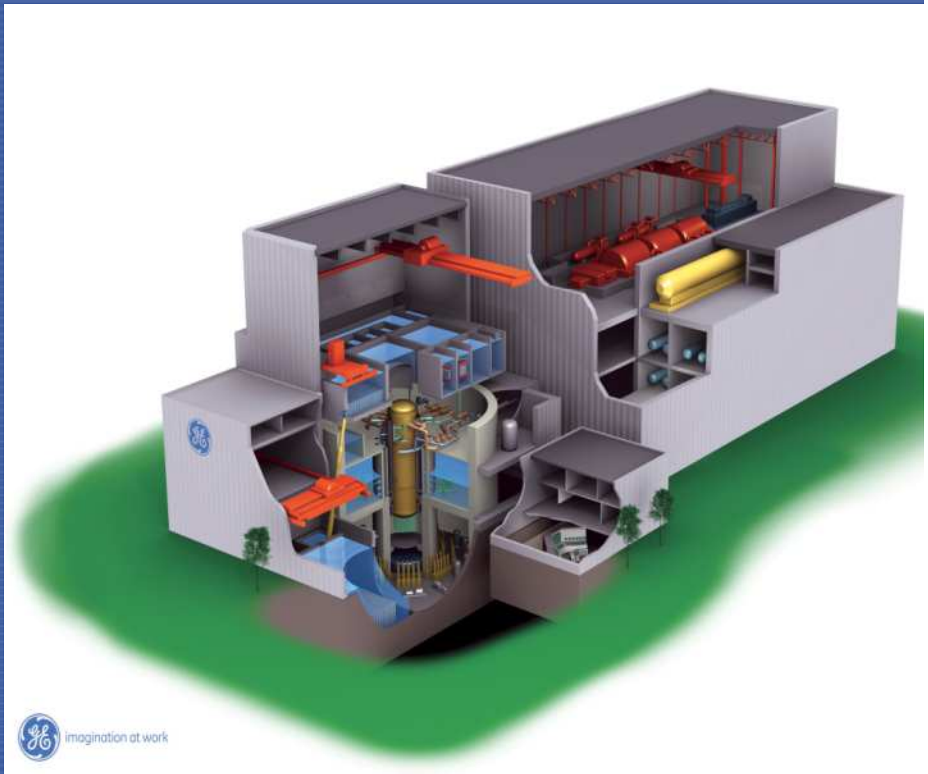
ESBWR

- Developed by GE
- Development began in 1993 to improve economics of SBWR
- 4500 MWt (~ 1550 MWe)
- In Design Certification review by the U.S.NRC – approved 10/2010
- Meets safety goals 100 times more stringent than current
- 72 hours passive capability
- Key Developments
  - NC for normal operation
  - Passive safety systems
    - Isolation condenser for decay heat removal
    - Gravity driven cooling with automatic depressurization for emergency core cooling
    - Passive containment cooling to limit containment pressure in LOCA
  - New systems verified by tests



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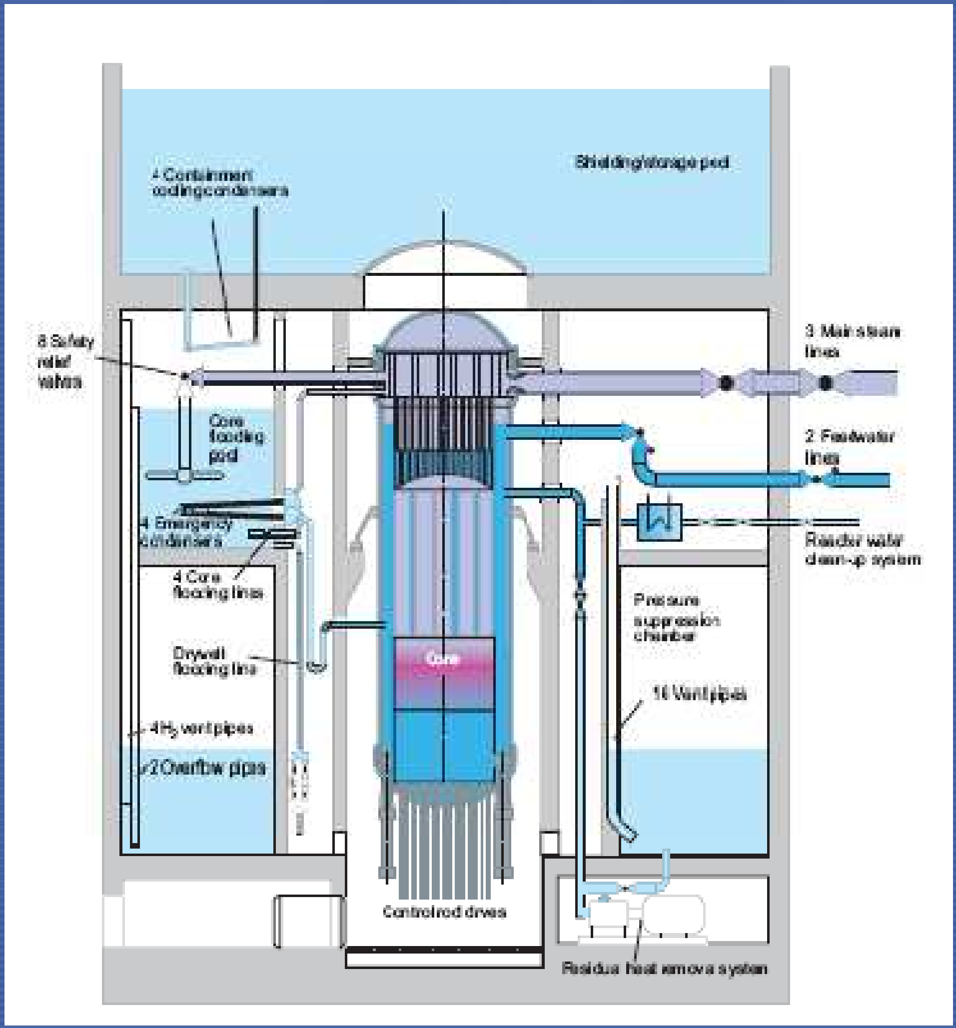
KERENA = SWR-1000

- AREVA & E.On
- Reviewed by EUR
- 1250+ MWe
- Uses internal re-circulation pumps
- Active & passive safety systems
- Offered for Finland-5
- Gundremingen reference plant
- New systems verified by test (e.g. FZ Jülich test of isolation condenser)



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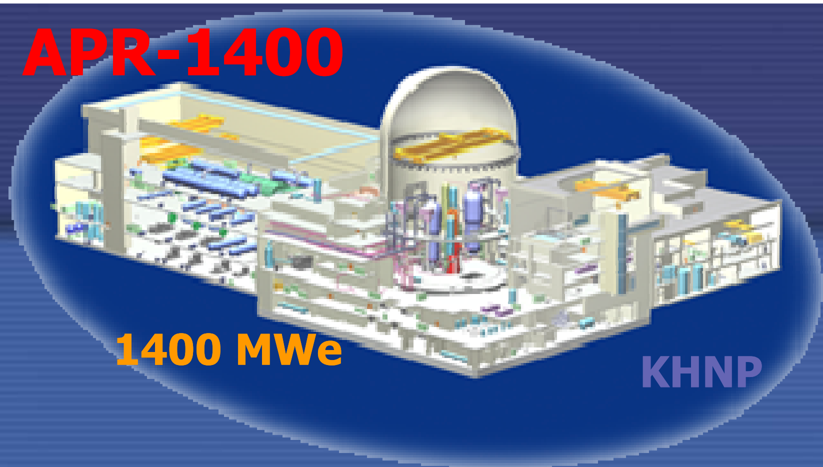
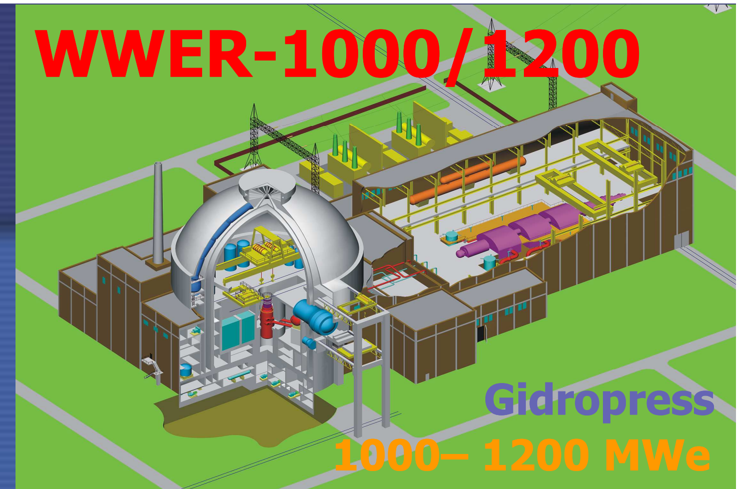
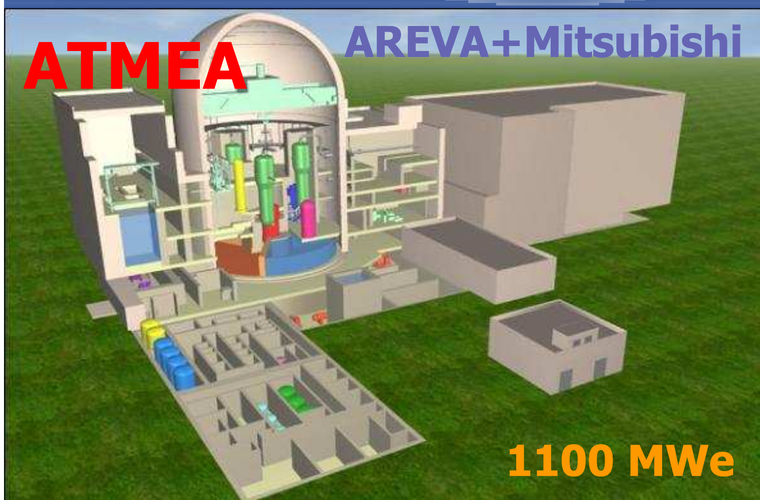
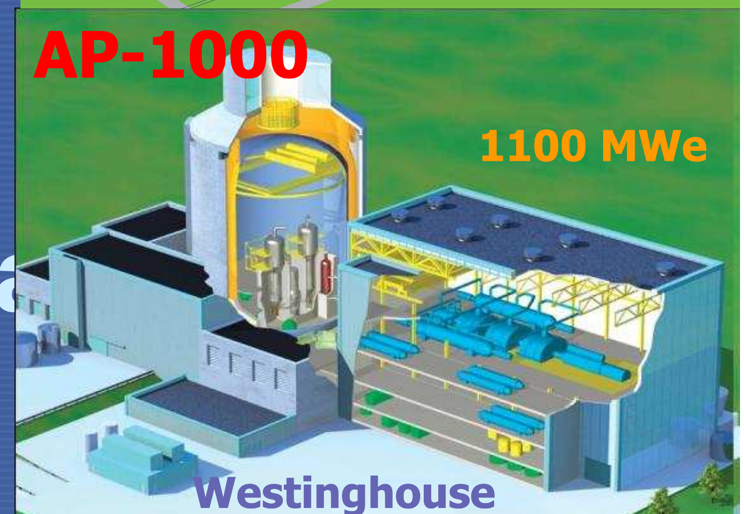

APR-1400
1400 MWe
KHNP

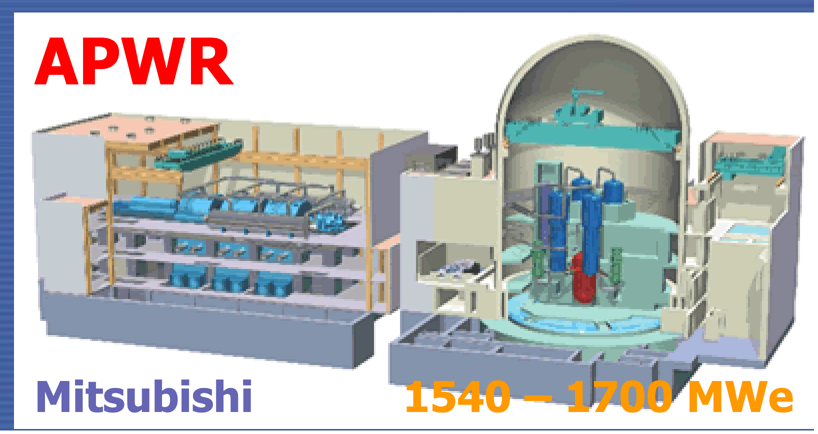

WWER-1000/1200
Gidropress
1000– 1200 MWe


ATMEA
AREVA+Mitsubishi
1100 MWe

Vater Rea

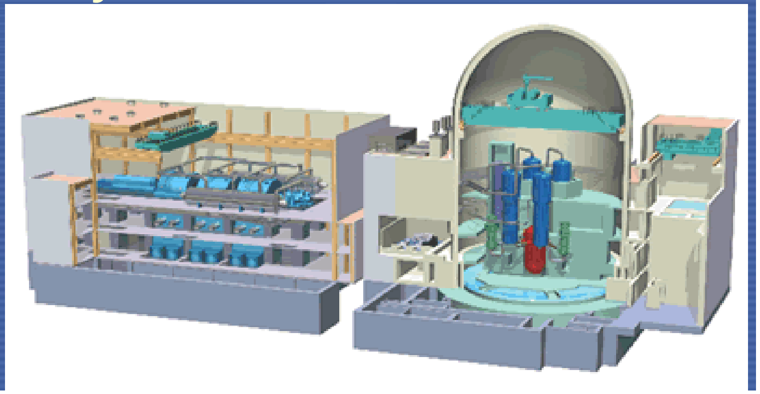

AP-1000
1100 MWe
Westinghouse


EPR
AREVA
1600+ MWe


APWR
Mitsubishi
1540 – 1700 MWe

Advanced Pressurized Water Reactor (APWR)

- Mitsubishi Heavy Industries & Japanese utilities
- 2x1540 MWe APWRs planned by JAPC at Tsuruga-3 & -4 and 1x1590 MWe APWR planned by Kyushu EPC at Sendai-3
  - Advanced neutron reflector (SS rings) improves fuel utilization and reduces vessel fluence
- 1700 MWe "US APWR" in Design Certification by the U.S.NRC
  - Evolutionary, 4-loop, design relying on a combination of active and passive safety systems (advanced Accumulator)
  - Full MOX cores
  - 39% thermal efficiency
  - Selected by TXU for Comanche Peak 3 and 4
- 1700 MWe "EU-APWR" to be evaluated by EUR



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EPR

Application

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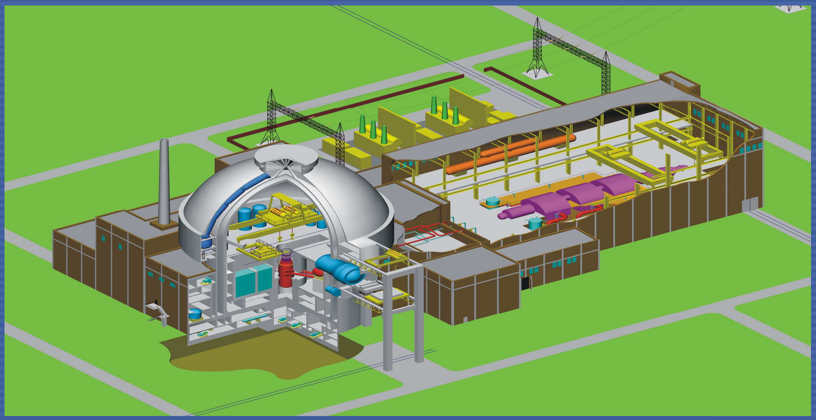
WWER-1000 / 1200 (AEP)

- The state-owned AtomEnergoProm (AEP), and its affiliates (including AtomStroyExport (ASE) et.al) is responsible for nuclear industry activities, including NPP construction
- Advanced designs based on experience of 23 operating WWER-440s & 27 operating WWER-1000 units
- Present WWER-1000 construction projects
  - Kudankulam, India (2 units)
  - Belene, Bulgaria (2 units)
  - Bushehr, Iran (1 unit)
- WWER-1200 design for future bids of large size reactors



- Tianwan
  - first NPP with corium catcher
  - Commercial operation: Unit-1: 5.2007; Unit-2: 8.2007
- Kudankulam-1 & 2
  - Commercial operation expected in 2010
  - Core catcher and passive SG secondary side heat removal to atmosphere

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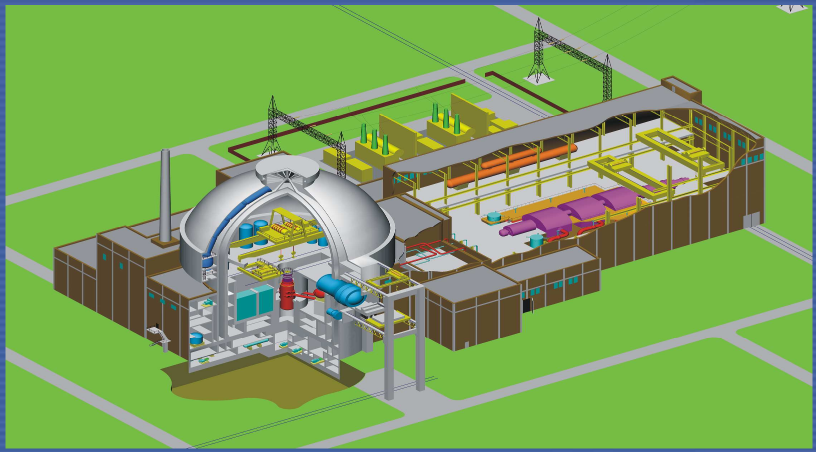
WWER-1200

Commissioning of 17 new WWER-1200s in Russia expected by 2020

- Novovoronezh – 2 units
- Leningrad – 4 units
- Volgodon – 2 units
- Kursk – 4 units
- Smolensk – 4 units
- Kola – 1 unit



- Uses combination of active and passive safety systems
- One design option includes core catcher; passive containment heat removal & passive SG secondary side heat removal
- 24 month core refuelling cycle
- 60 yr lifetime
- 92% load factor

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APR-1400

- Developed in Rep. of Korea (KHNP and Korean Industry)
- 1992 - development started
- Based on CE's System 80+ design (NRC certified)
- 1400 MWe - for economies of scale
- Incorporates experience from the 1000 MWe Korean Standard Plants
- Relies primarily on well proven active safety systems
- First units will be Shin-Kori 3,4
  - completion 2013-14
- Design Certified by Korean Regulatory Agency in 2002
- 4 units to be built in UAE

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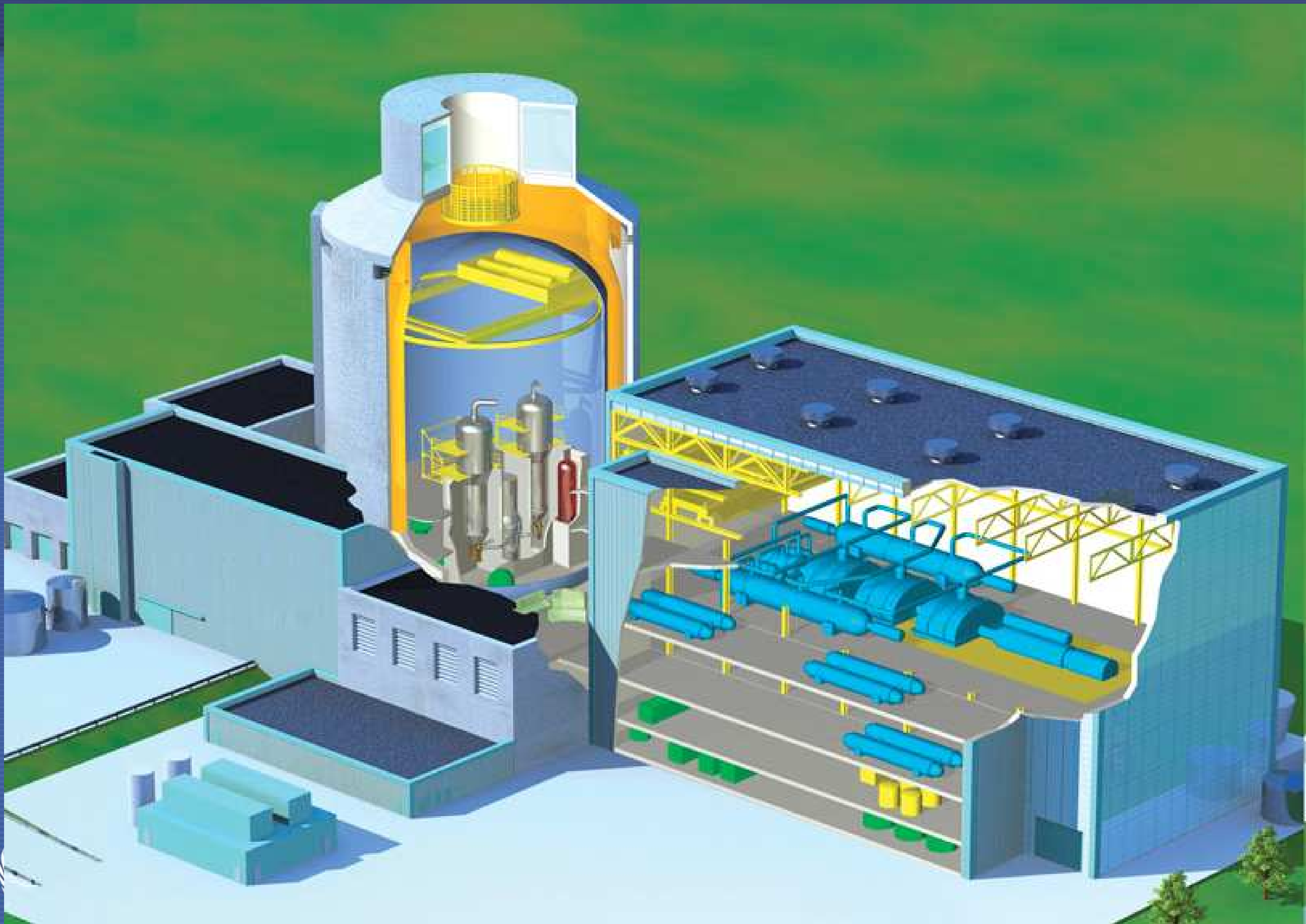
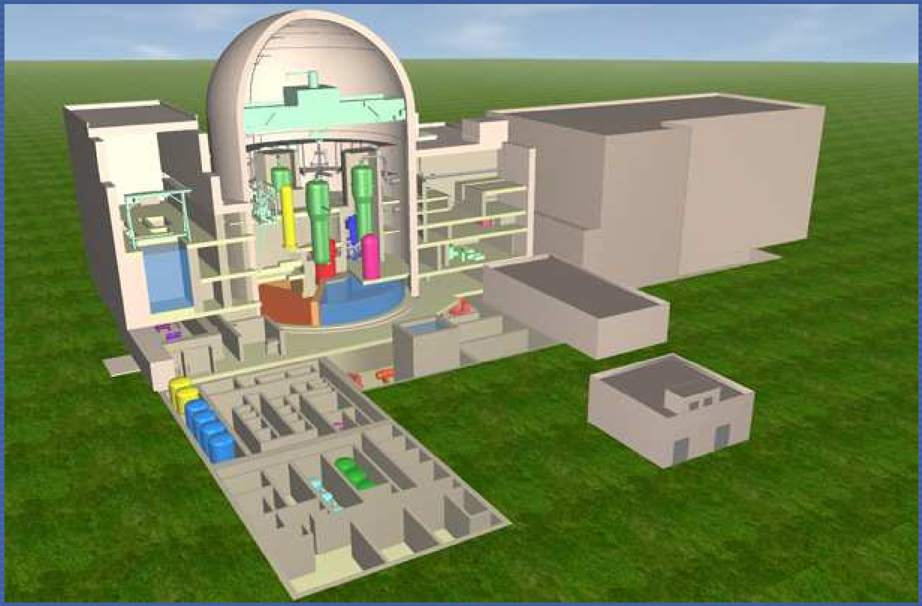
AP-600 and AP-1000



ATMEA1

- 1100 MWe, 3 loop plant
- Combines AREVA & Mitsubishi PWR technologies
- Relies on active safety systems & includes core catcher
- Design targets:
  - 60 yr life
  - 92% availability
  - 12 to 24 month cycle; 0-100% MOX



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Chinese advanced PWRs CPR (CGNPC) and CNP (CNNC)

- CPR-1000
  - Evolutionary design based on French 900 MWe PWR technology
  - Reference plant: Lingau-1&2 (NSSS Supplier: Framatome; commercial operation in 2002)
  - Lingau-3&4 are under construction (with > 70% localization of technology; NSSS Supplier: Dongang Electric Corporation);
  - Now a Standardized design
  - Hongyanhe 1,2,3,4; Ningde 1; Yangjiang 1,2; Fuquing 1,2; Fanjiashan 1&2 under construction; more units planned: Ningde 2,3,4 and Yangjiang 3,4,5,6

- CNP-650
  - Upgrade of indigenous 600 MWe PWRs at Qinshan (2 operating & 2 under construction)

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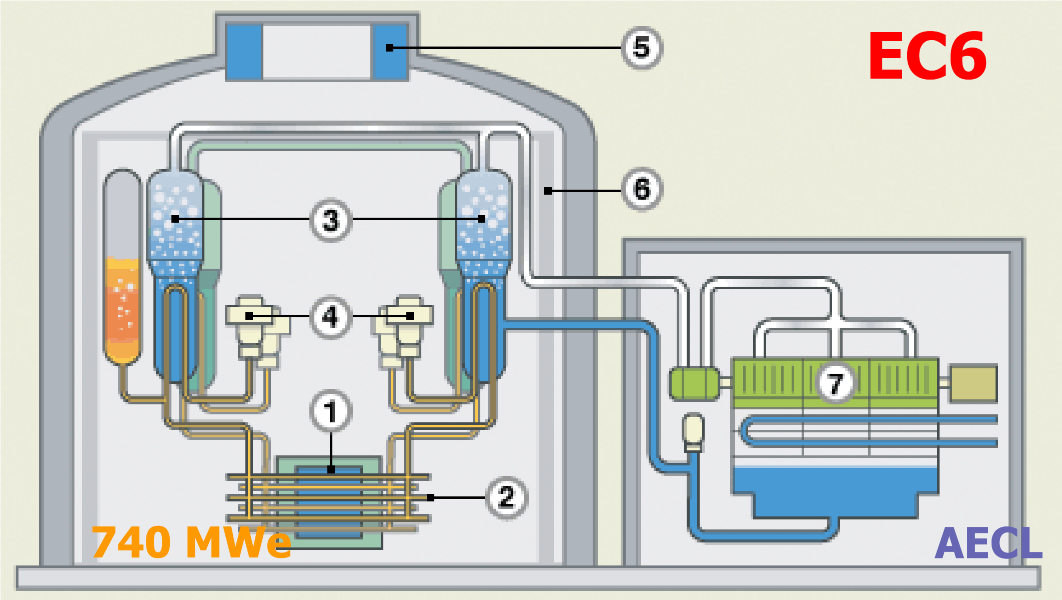
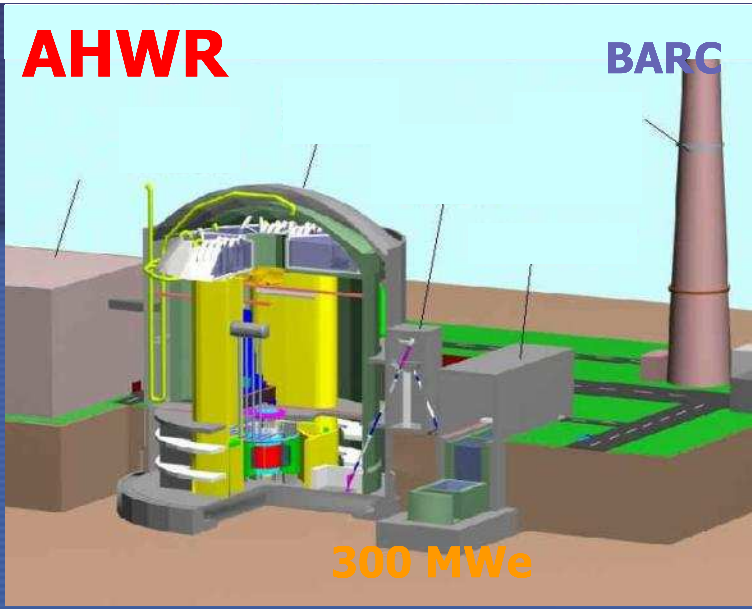
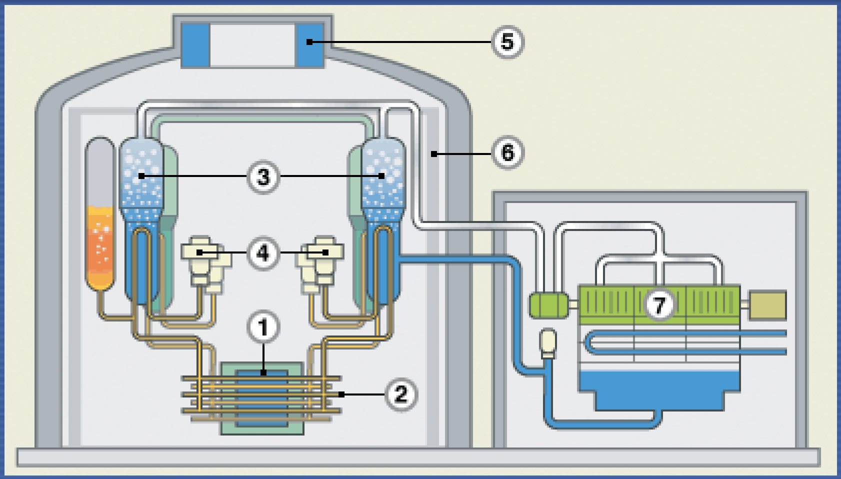
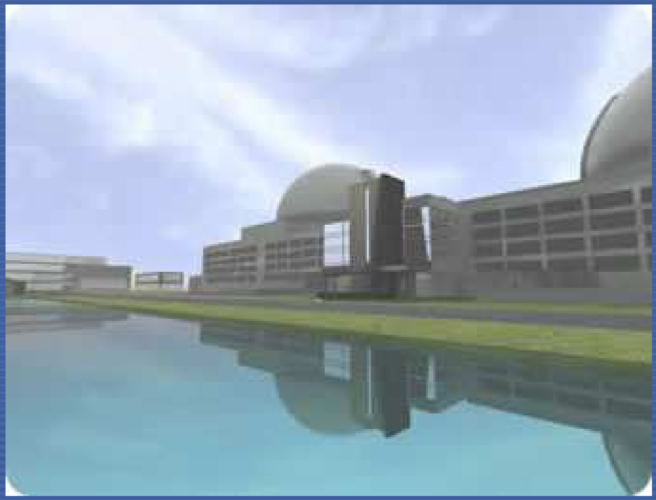




Heavy Water Reactors (HWR)

ACR-700 & ACR-1000





- AECL
- 740 MWe Enhanced CANDU-6
- 1000 MWe Advanced CANDU reactor
- 284 / 520 horizontal channels
- Low enriched uranium– 2.1%,
- 60 yr design life
- Continuous refueling
- Combination of active and passive safety systems
- CNSC has started "pre-project" design review
- Energy Alberta has filed *an Application for a License to Prepare Site* with the CNSC -- for siting up to two twin-unit ACR-1000s --- commissioning by ~2017
- 30 CANDU operating in the world
  - 18 Canada (+2 refurbishing, +5 decommissioned)
  - 4 South Korea
  - 2 China
  - 2 India (+13 Indian-HWR in use, +3 Indian-HWR under construction)
  - 1 Argentina
  - 2 Romania (+3 under construction)
  - 1 Pakistan

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India's HWR

- 540 MWe PHWR [evolution from current 220 MWe HWRs]
  - » Nuclear Power Corporation of India, Ltd.
  - » First units: Tarapur-3 & -4 connected to grid (2005 & 6)

- 700 MWe PHWR [further evolution – economy of scale]
  - » NPCIL
  - » Regulatory review in progress
  - » Use of Passive Decay Heat Removal System; reduced CDF from PSA insights
  - » Better hydrogen management during postulated core damage scenario
  - » First units planned at Kakrapar & Rawatbhata

- 300 MWe Advanced HWR
  - » BARC
  - » for conversion of Th232 or U238 (addressing sustainability goals)
  - » vertical pressure tube design with natural circulation

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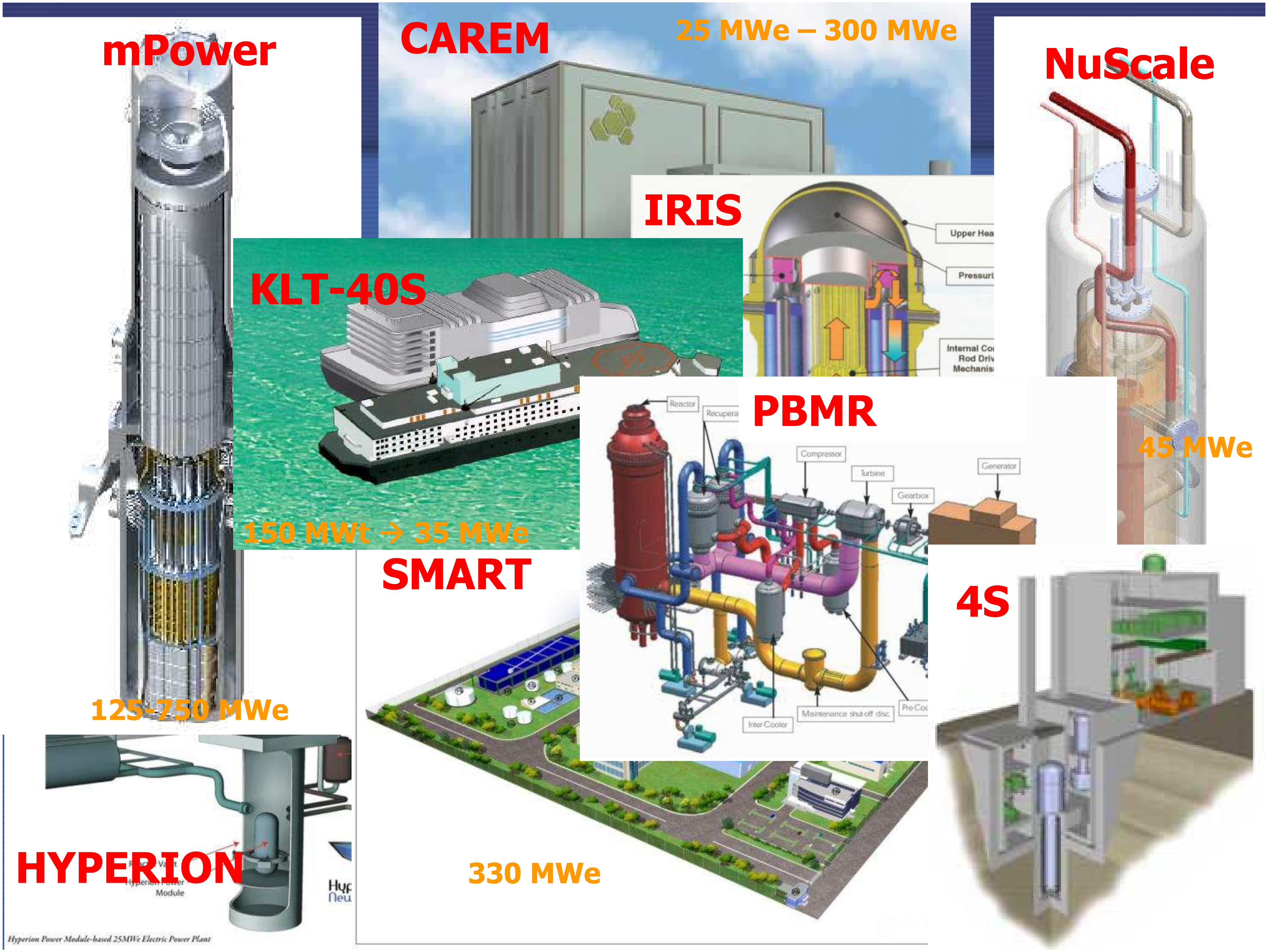
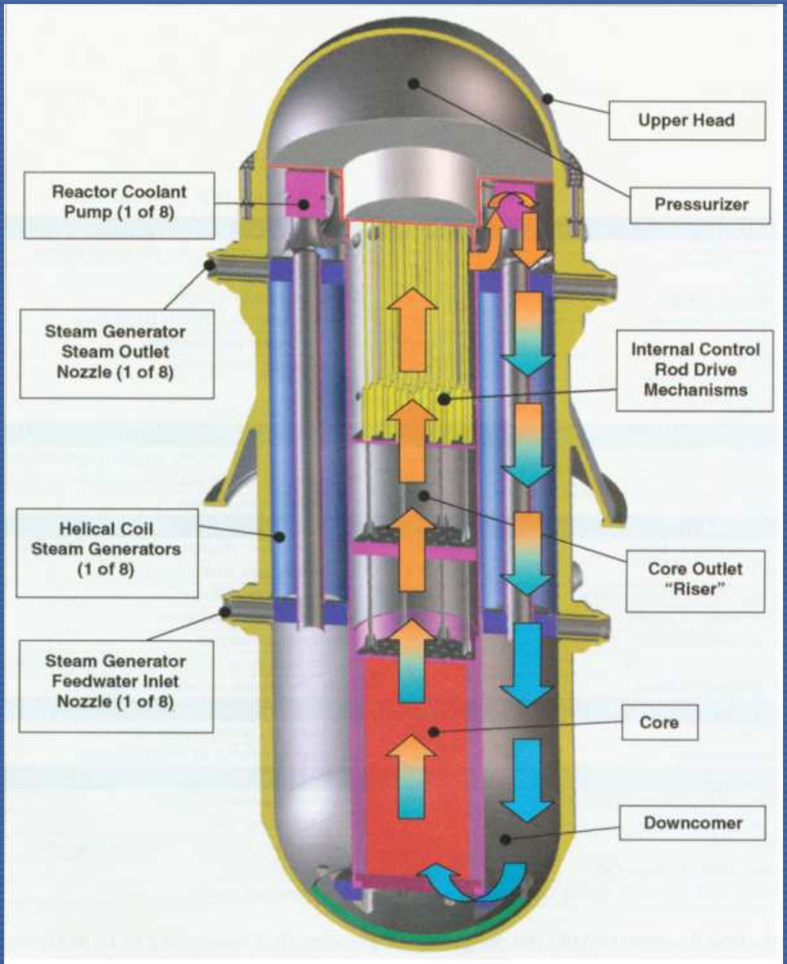

mPower
CAREM
25 MWe – 300 MWe
NuScale
IRIS
KLT-40S
PBMR
Reactor
Compressor
Turbine
Gearbox
Generator
Inter-Cooler
Maintenance shut-off disc
45 MWe
150 MWt → 35 MWe
SMART
4S
125-750 MWe
HYPERION
Module
330 MWe
Hyperion Power Module-based 25MWe Electric Power Plant

IRIS (International Reactor Innovative and Secure)

- Westinghouse
- 100-335 MWe
- Integral design
- Design and testing Involves 19 organizations (10 countries)
- Pre-application review submitted to the USNRC in 2002
- To support Design Certification, large scale (~6 MW) integral tests are planned at SPES-3 (Piacenza, IT)
  - Construction start – late 2009
- Westinghouse anticipates Final Design Approval (~2013)



SMART

- Korea Atomic Energy Research Institute
- 330 MWe
- Used for electric and non-electric applications
- Integral reactor
- Passive Safety

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CAREM (Central Argentina de Elementos Modulares)

- Developed by INVAP and Argentine CNEA
- Prototype: 25 MWe
- Expandable to 300 MWe
- Integral reactor
- Passive safety
- Used for electric and non-electric applications
- Nuclear Safety Assessment under development
- Prototype planned for 2012 in Argentina's Formosa province

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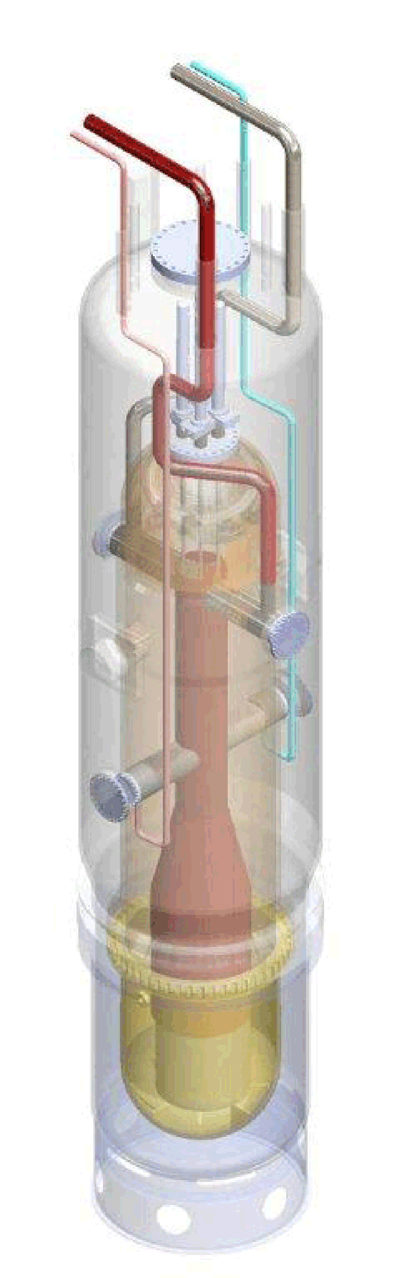
NuScale

- Oregon State University (USA)
- 45 MWe
- 90% Capacity Factor
- Integral reactor
- Modular, scalable
- Passive safety
- Online refueling
- To file for Design Certification with US NRC in 2010.



B&W mPower

- Integral reactor
- Scalable, modular
- 125 – 750 MWe
- 5% enriched fuel
- 5 year refueling cycle
- Passive safety
- Lifetime capacity of spent fuel pool

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Floating Reactors

- Provide electricity, process heat and desalination in remote locations
- KLT-40S (150 MWt → 35 MWe)
- VBER-150 (350 MWt → 110 MWe)
- VBER-300 (325 MWe)

Construction of pilot plant (2 units) started April 2007

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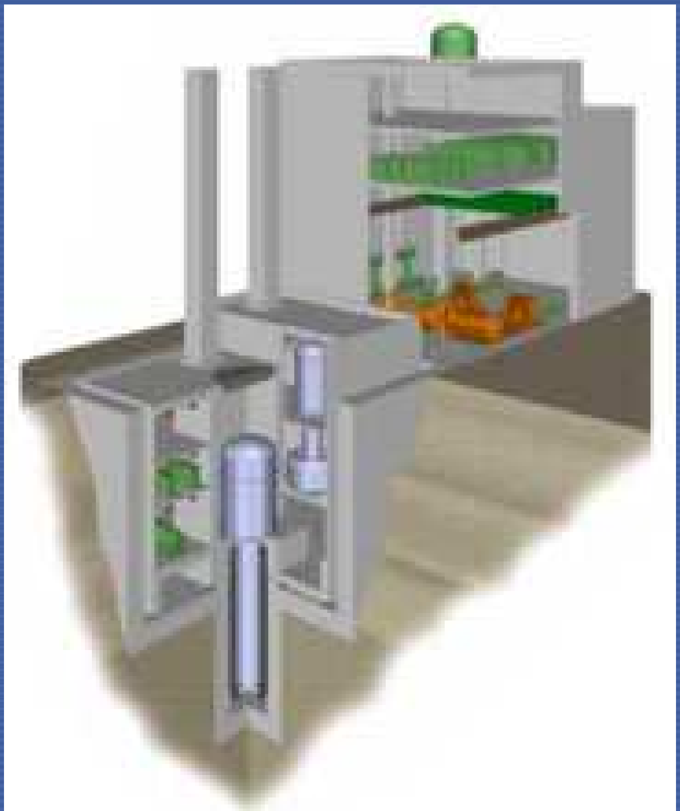
4S (Super Safe, Small and Simple)

- Toshiba & CRIEPI of Japan
- 50 MWe
- Sodium Cooled Fast Reactor
- 10 – 30 year refueling period
- Submitted for US NRC Pre Application Review
- Proposed for Galena, Alaska



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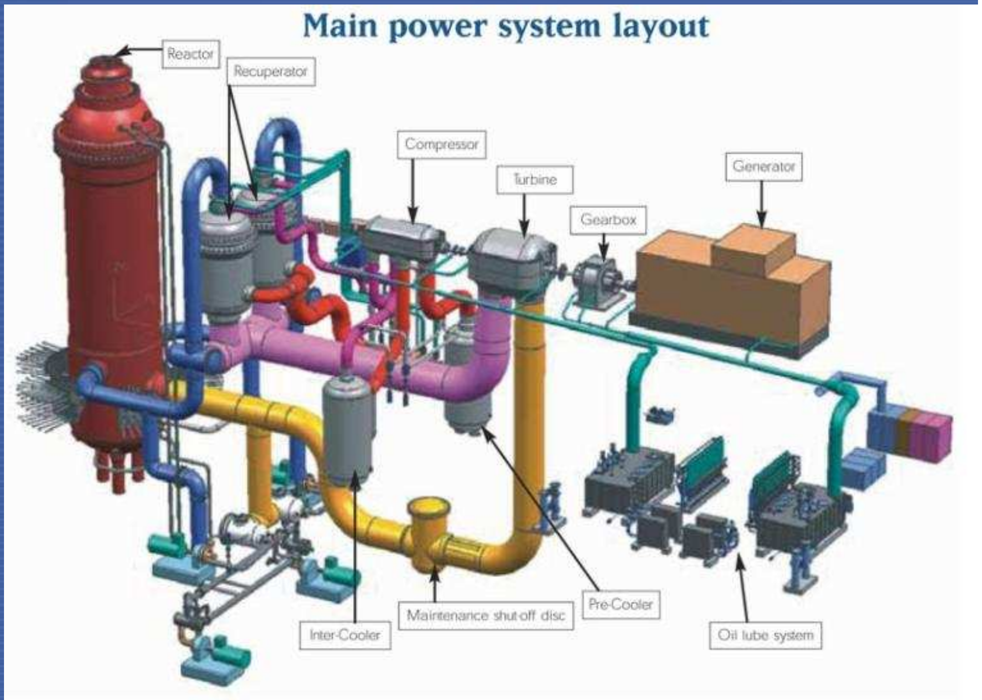
PBMR (Pebble Bed Modular Reactor)

- ESKOM, South Africa Government, Westinghouse
- Helium Gas Cooled
- 165 MWe
- Electrical and non-electrical applications



GAS-COOLED REACTOR DEVELOPMENT

- More than 1400 reactor-years experience
- CO_2 cooled
  - 22 reactors generate most of the UK's nuclear electricity
  - also operated in France, Japan, Italy and Spain
- Helium cooled
  - operated in UK (1), Germany (2) and the USA (2)
  - current test reactors:
    - 30 MW(th) HTTR (JAERI, Japan)
    - 10 MW(th) HTR-10 (Tsinghua University, China)
- In South Africa a small 165 MWe prototype plant is planned
- Russia, in cooperation with the U.S., is designing a plant for weapons Pu consumption and electricity production
- France, Japan, China, South Africa, Russia and the U.S. have technology development programmes

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Fast Reactor Development

- **France:**
  - Conducting tests of transmutation of long lived waste & use of Pu fuels at Phénix (shutdown planned for 2009)
  - Designing 300-600 MWe Advanced LMR Prototype “ASTRID” for commissioning in 2020
  - Performing R&D on GCFR
- **Japan:**
  - MONJU restart planned for 2009
  - Operating JOYO experimental LMR (Shutdown for repair)
  - Conducting development studies for future commercial FR Systems
- **India:**
  - Operating FBTR
  - Constructing 500 MWe Prototype Fast Breeder Reactor (commissioning 2010)
- **Russia:**
  - Operating BN-600
  - Constructing BN-800
  - Developing other Na, Pb, and Pb-Bi cooled systems
- **China:**
  - Constructing 25 MWe CEFR – criticality planned in 2009
- **Rep. of Korea:**
  - Conceptual design of 600 MWe Kalimer is complete
- **United States**
  - Under GNEP, planning development of industry-led prototype facilities:
    - Advanced Burner Reactor
    - LWR spent fuel processing

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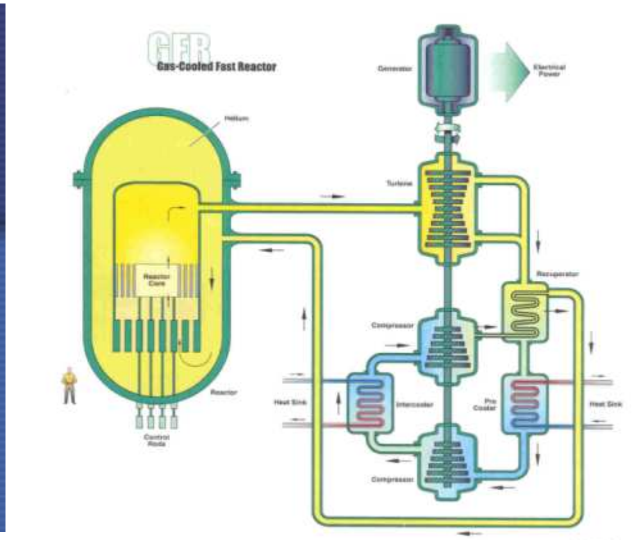
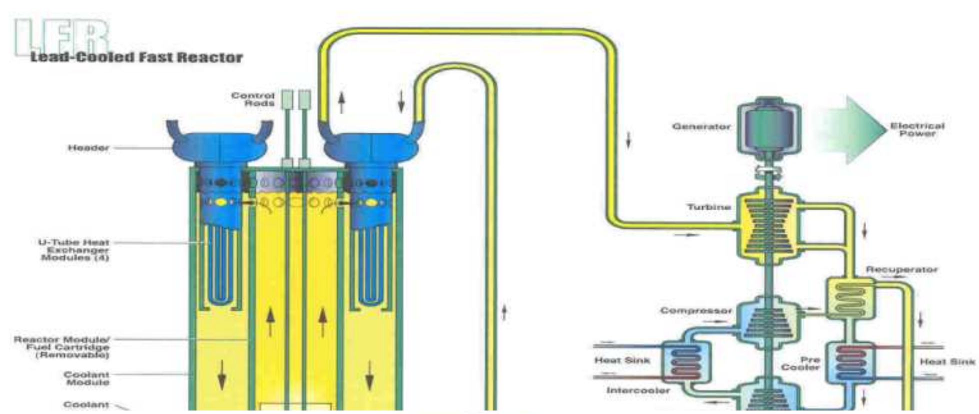
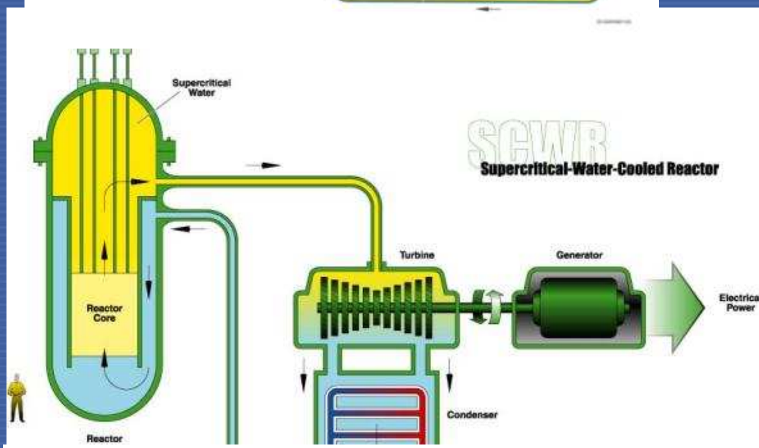
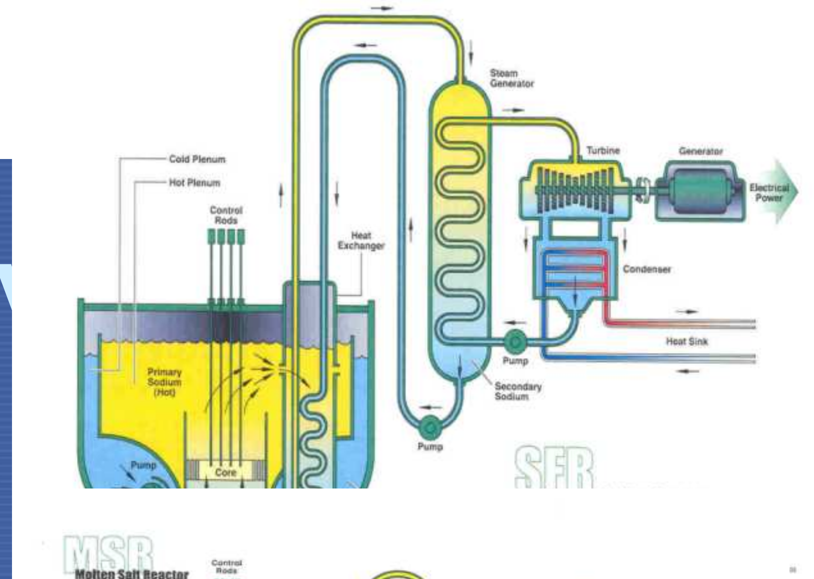
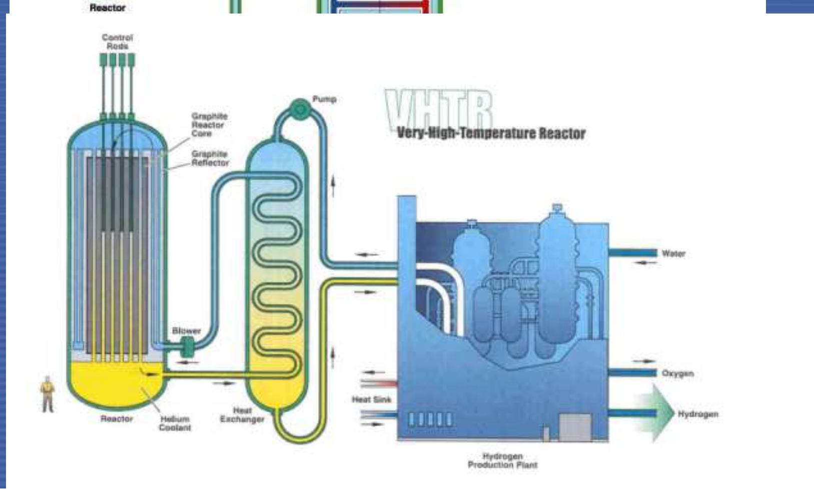

GFR
Gas-Cooled Fast Reactor
Generator
Electrical Power
Helium
Turbine
Reactor Core
Recuperator
Compressor
Reactor
Heat Sink
Intercooler
Pre Cooler
Heat Sink
Compressor
Control Rods

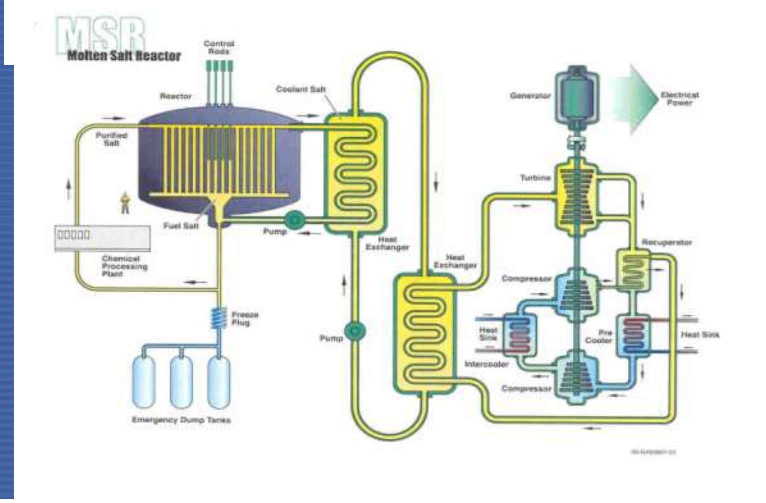

LFR
Lead-Cooled Fast Reactor
Control Rods
Header
U-Tube Heat Exchanger Modules (4)
Reactor Module/ Fuel Cartridge (Removable)
Coolant Module
Coolant
Generator
Electrical Power
Turbine
Recuperator
Compressor
Heat Sink
Pre Cooler
Heat Sink
Intercooler


Supercritical Water
SCWR
Supercritical-Water-Cooled Reactor
Reactor Core
Turbine
Generator
Electrical Power
Condenser
Reactor

on IV


Steam Generator
Cold Plenum
Hot Plenum
Control Rods
Heat Exchanger
Turbine
Generator
Electrical Power
Condenser
Heat Sink
Pump
Primary Sodium (Hot)
Secondary Sodium
Pump
Pump
Core
SFR


Control Rods
Graphite Reactor Core
Graphite Reflector
Pump
VHTR
Very-High-Temperature Reactor
Water
Blower
Oxygen
Heat Sink
Hydrogen
Reactor
Helium Coolant
Heat Exchanger
Hydrogen Production Plant


MSR
Molten Salt Reactor
Control Rods
Reactor
Coolant Salt
Generator
Electrical Power
Purified Salt
Turbine
Fuel Salt
Pump
Heat Exchanger
Recuperator
Chemical Processing Plant
Heat Exchanger
Compressor
Freeze Plug
Pump
Heat Sink
Pre Cooler
Heat Sink
Intercooler
Compressor
Emergency Dump Tanks

Generation IV Reactor Designs

- Several design concepts are under development to meet goals of
  - Economics
  - Sustainability
  - Safety and reliability
  - Proliferation resistance and physical protection
- All concepts (except VHTR) are based on closed fuel cycle
- Concepts include small, modular approaches
- Most concepts include electrical and non-electrical applications
- Significant R&D efforts are still required
- International cooperation needed for pooling of resources

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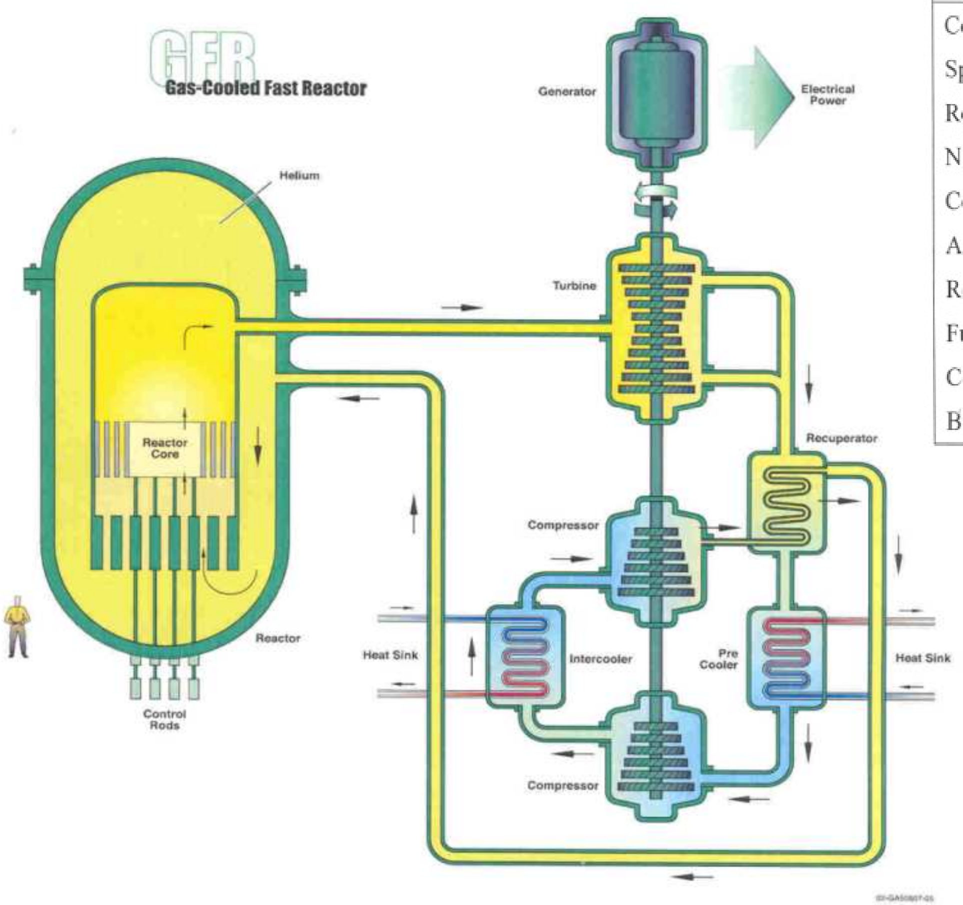
Generation IV Reactor Designs

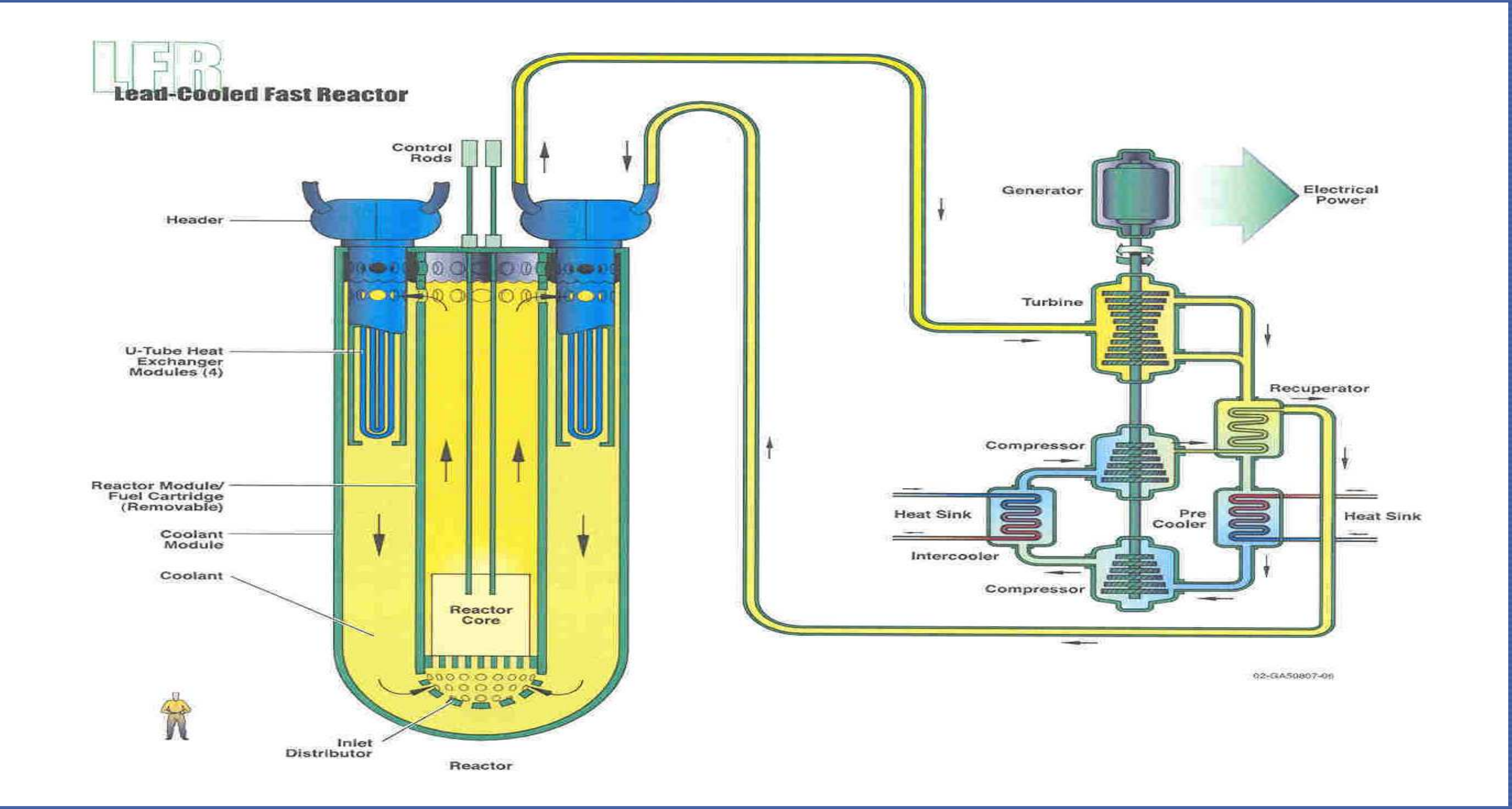
- Gas Cooled Fast Reactors (GFR)
- Very High Temperature Reactor (VHTR)
- Super-Critical Water Cooled Reactor (SCWR)
- Sodium Cooled Fast Reactor (SFR)
- Lead-Cooled Fast Reactor (LFR)
- Molten Salt Reactor (MSR)

Gas Cooled Fast Reactor



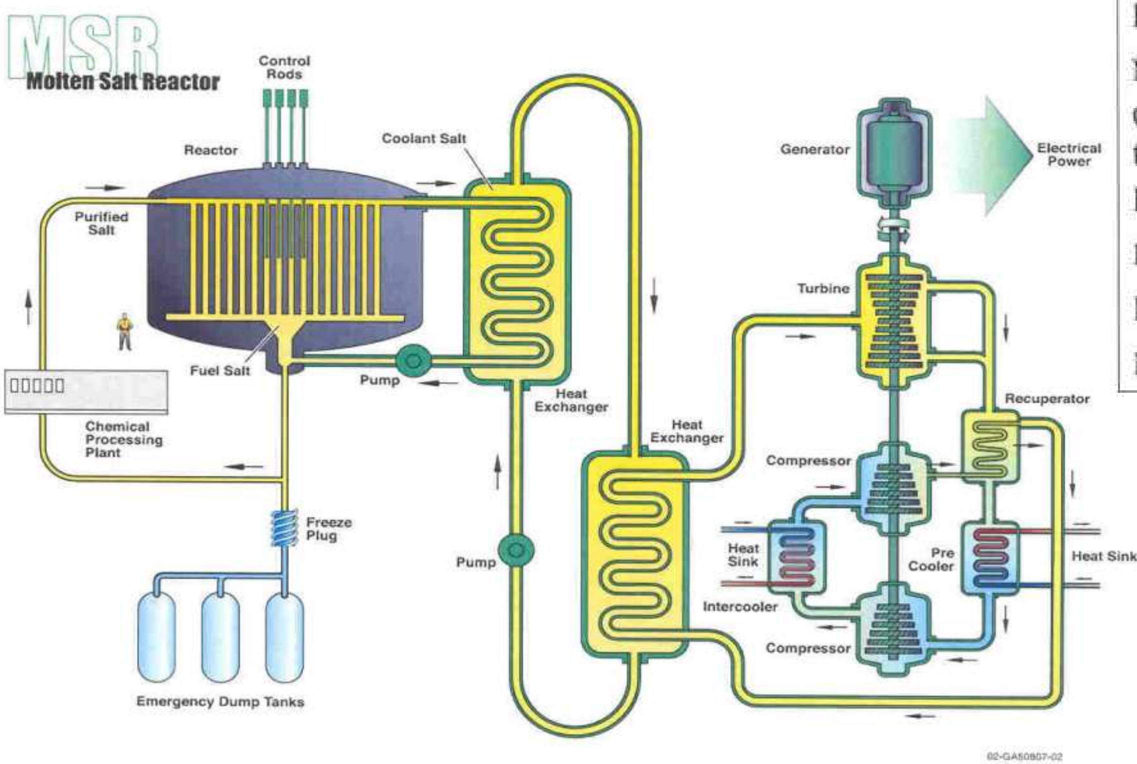
Reactor parameter	Reference Value
Coolant	Helium
Spectrum	Fast
Reactor power	600 MWth
Net plant efficiency (Brayton cycle)	48%
Coolant inlet/outlet temperature and pressure	490°C/850°C at 90 bar
Average power density	100 $MWth/m^3$
Reference fuel compound	UPuC/SiC with about 20% Pu content
Fuel cycle	Closed
Conversion ratio	Self-sufficient
Burn up	5% FIMA

Lead Cooled Fast Reactor



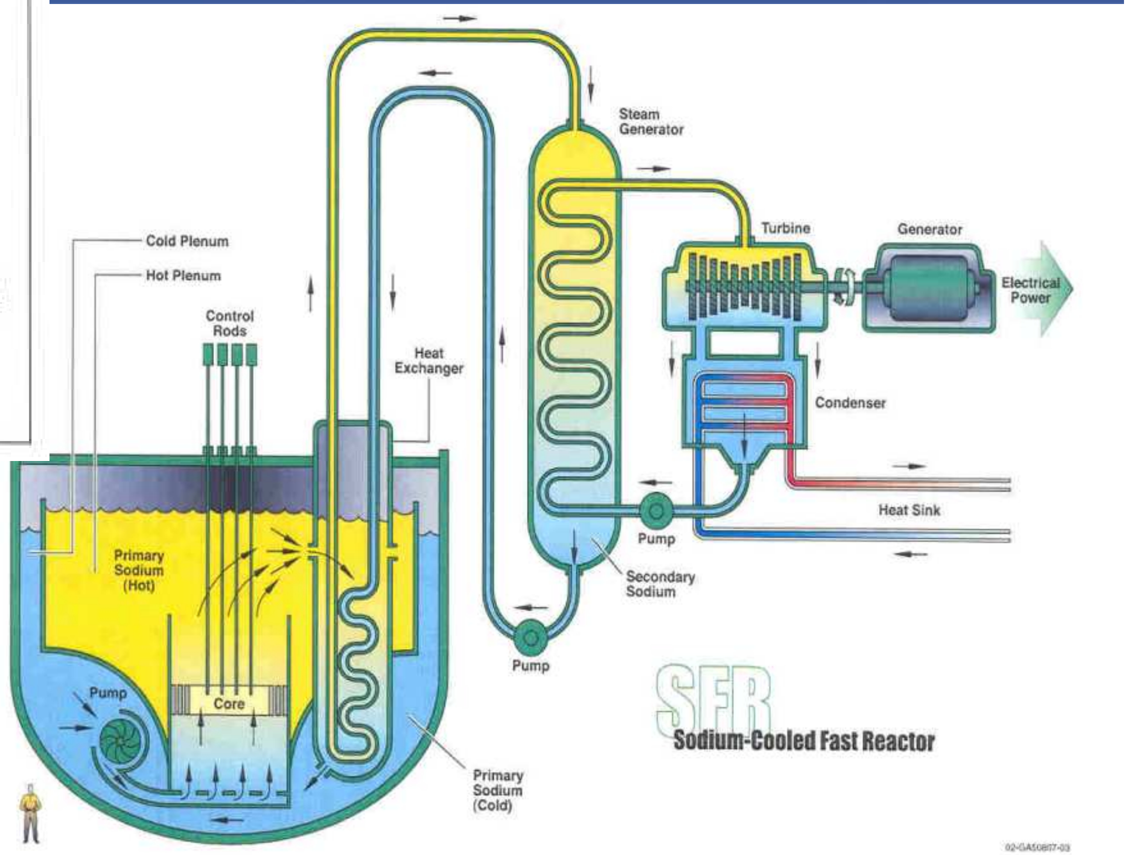
Molten Salt Reactor

Reactor parameter	Reference Value
Coolant	Molten Salt
Spectrum	Thermal
Reactor power	1000 MWe
Net plant efficiency	44 to 50 %
Coolant inlet/outlet temperature and pressure	565 - 750°C (850°C for hydrogen production)
Fuel	Uranium/Plutonium Fluoride
Fuel cycle	Closed
Power Density	22MWth/m^3
Moderator	Graphite

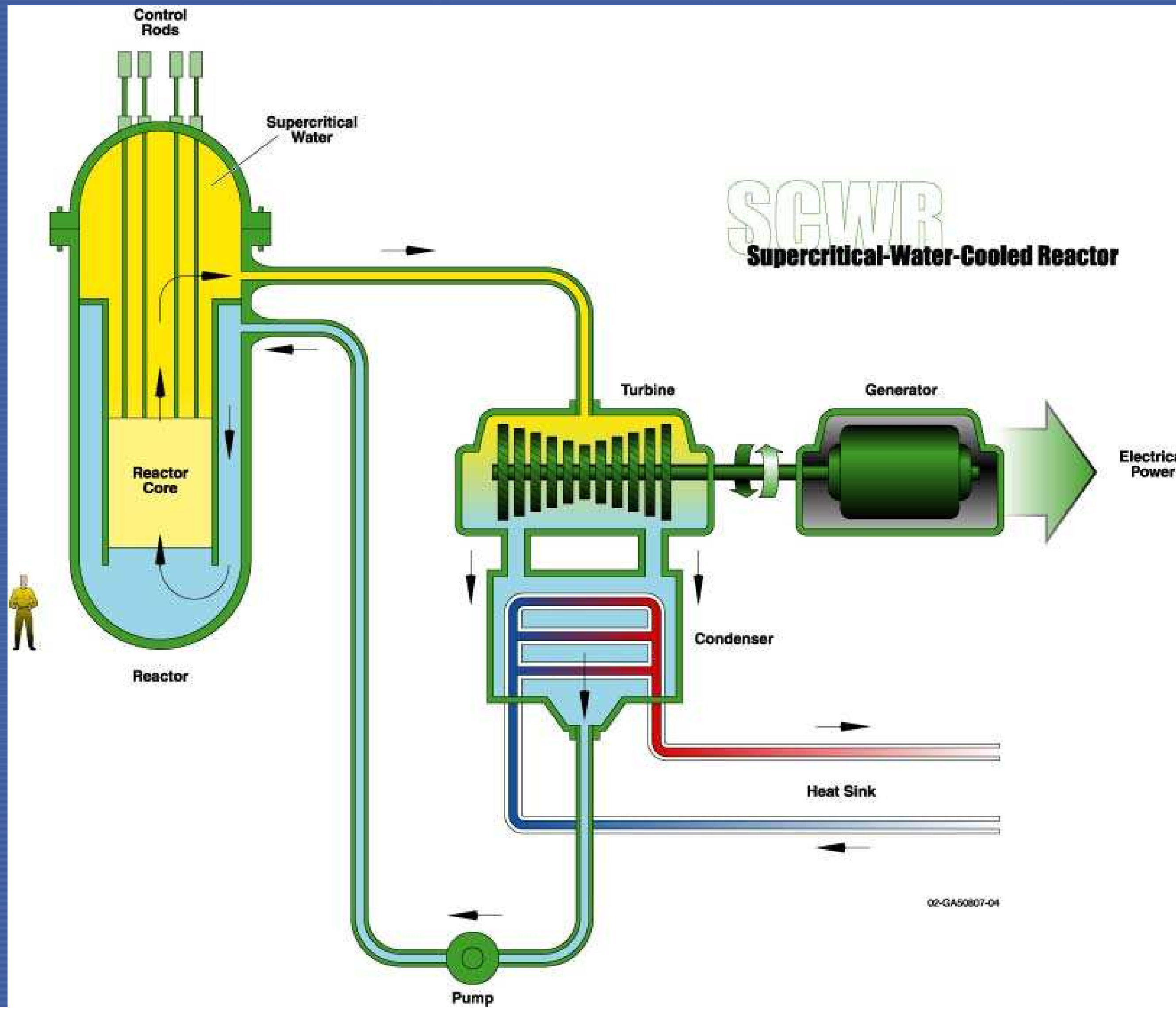


Sodium cooled Fast Reactor

Reactor parameter	Reference Value
Coolant	Sodium
Spectrum	Fast
Reactor power	1000-5000 MWth
Design	Pool type
Coolant outlet temperature and pressure	530-550°C, 1 bar
Fuel	Oxide or metal alloy
Fuel cycle	Closed
Average Burn-up	About 150-200 GWD/MTHM
Conversion ratio	0.5-1.30
Average Power Density	350 MWth/m^3

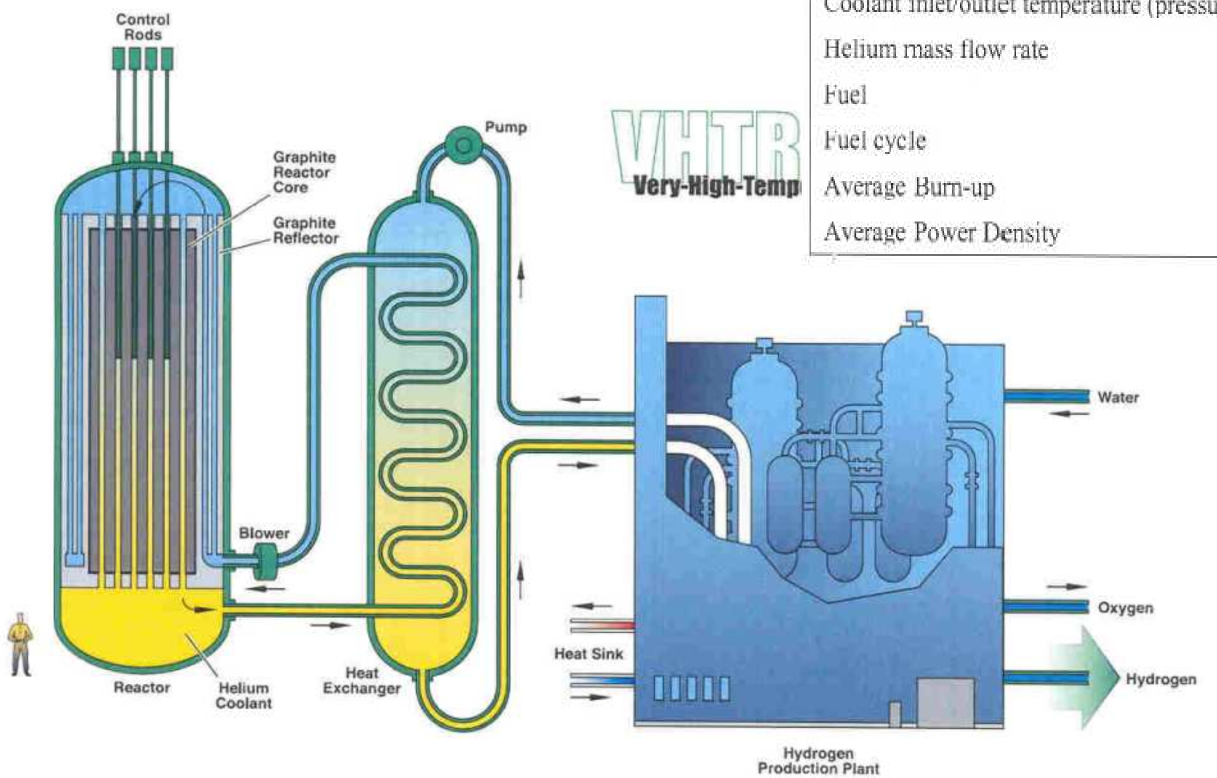


Super-Critical Water Cooled Reactor

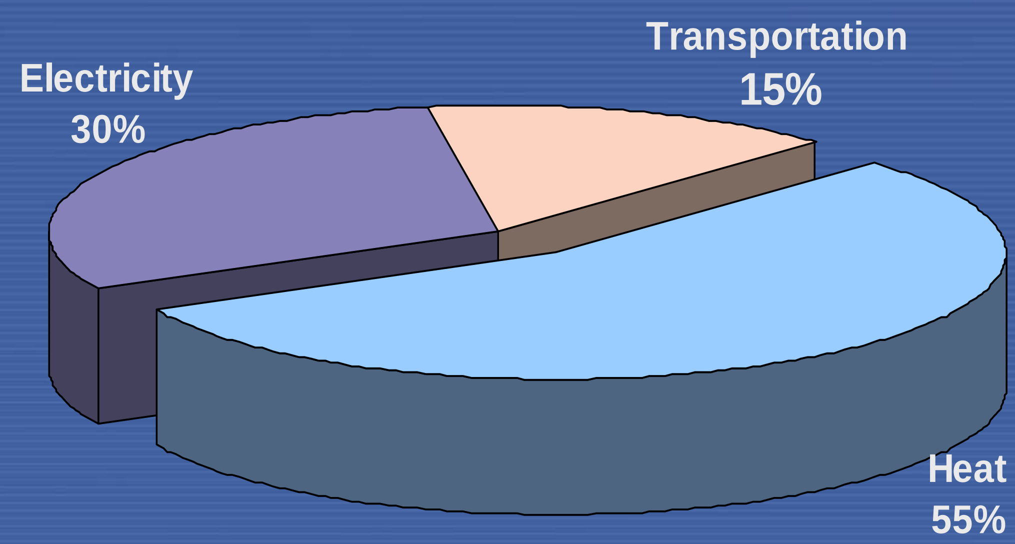


Very High Temperature Reactor

Reactor parameter	Reference Value
Coolant	Helium
Spectrum	Thermal
Reactor power	600 MWth
Coolant inlet/outlet temperature (pressure)	640/1000°C (depending on process)
Helium mass flow rate	320 Kg/s
Fuel	UO_2 in ZrC-coated particles in blocks, pins or pebbles
Fuel cycle	Open
Average Burn-up	150-200GWD/MTHM
Average Power Density	6-10 MWth/m^3



The potential for non-electric applications of nuclear energy is large



Energy consumption by application

Advanced Applications of Nuclear Energy

- Sea-water desalination
- District heating
- Heat for industrial processes
- Hydrogen production
  - At “fuelling stations” by water electrolysis
  - At central nuclear stations by
    - high temperature electrolysis
    - thermo-chemical processes
    - hybrid processes
- Coal gasification
- Enhanced oil recovery (e.g. from oil shale and tar sands)
- Electricity for Plug-in Hybrid Vehicles

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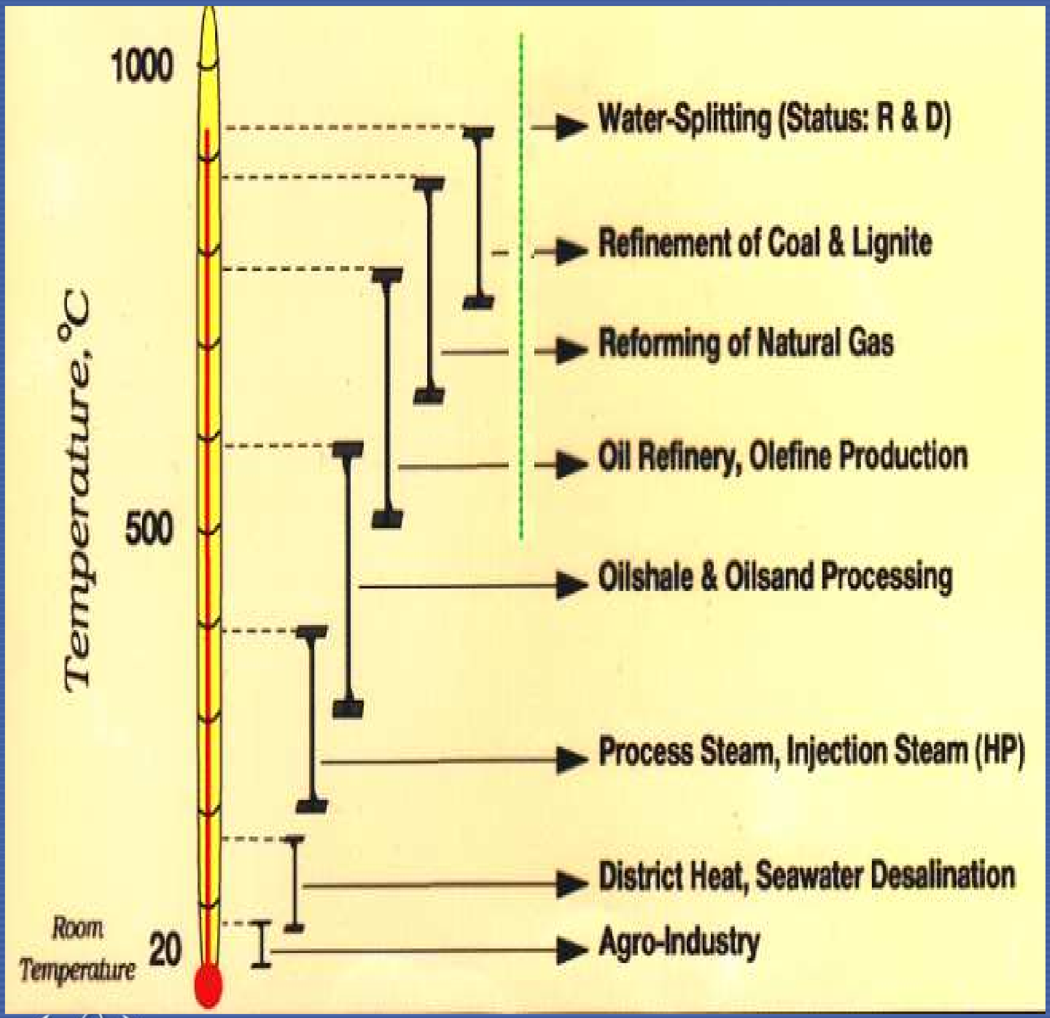
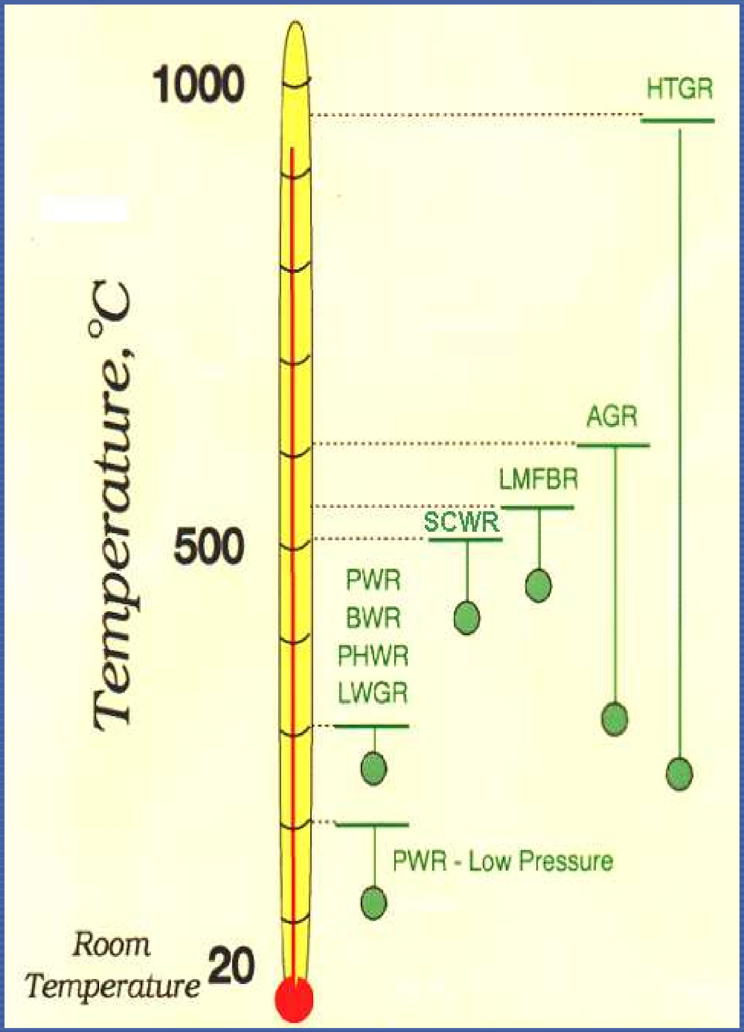
Nuclear Plants Can Provide the Heat Required for Many Processes





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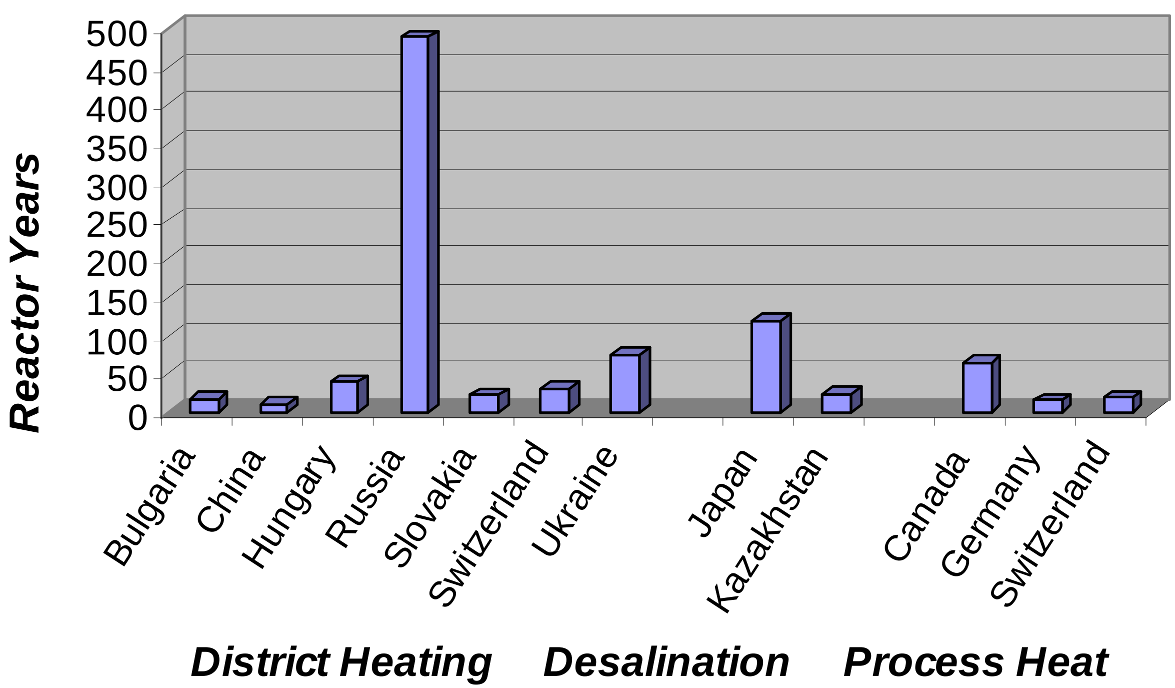
Non-Electrical Applications

- Today 441 NPPs in operation worldwide
- 30 are being used for cogeneration (about 5 GW(th))
- About 700 reactor-years of experience

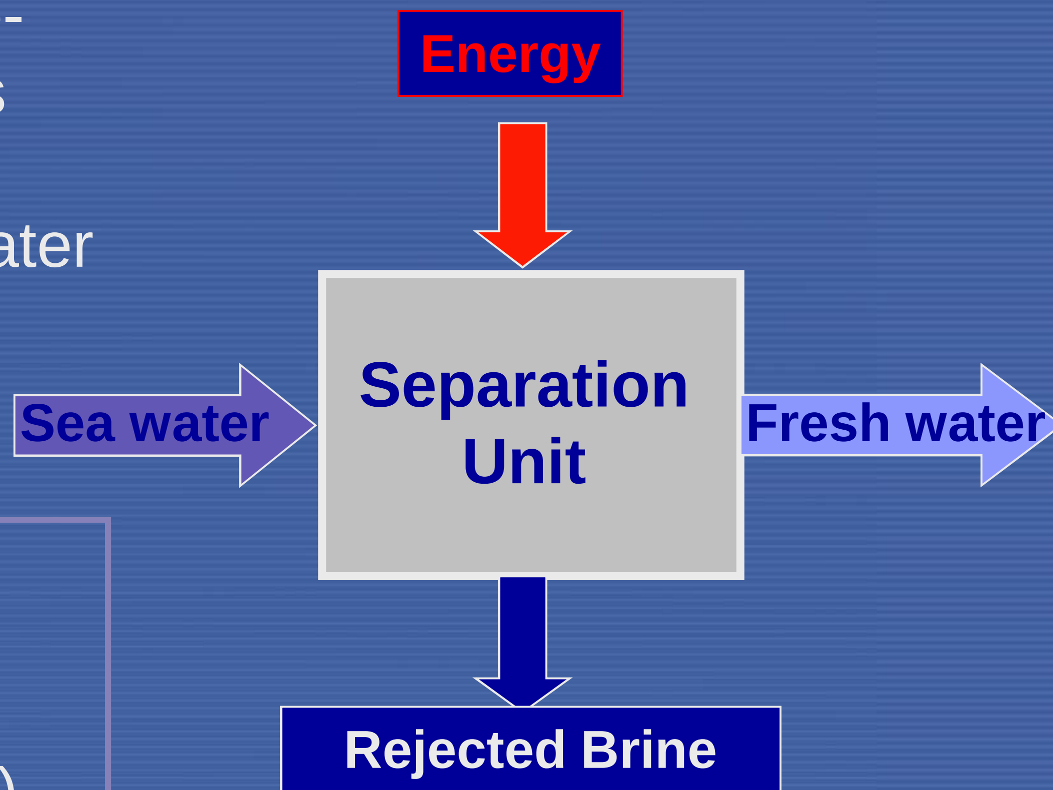


Characteristics of the heat market

- **District heating**
  - seasonal fluctuation in demand
  - unlikely to be in base-load operation
  - limited distribution line, typically about 20-30 km
  - low grade steam/hot water
- **Industrial process heat**
  - high, medium and low temperature
  - likely to be base-load, little seasonal change
  - high reliability as a source
  - could be away from population center
  - short distribution line

Desalination

Fully developed to a large-scale commercial process providing
38 Million m³/d of fresh water in 120 countries



Distillation
Multi-stage flash (MSF)
Multi effect (MED)
Vapor compression (TVC)

Membrane separation
Reverse osmosis (RO)

Reactor Types and Desalination Processes

Reactor type	Location	Capacities (cu.m./d)	Status
LMFR	Kazakhstan (Aktau)	80,000	in service till 1999
PWRs	Japan (Ohi, Takahama, Ikata, Genkai) Rep. of Korea Argentina Russia	1,000 – 2,000 40,000 12,000	in service with operating experience of over 125 reactor-years under design under design (floating unit)
BWR	Japan (Kashiwazaki)		never in service following testing in 1980s, due to alternative freshwater sources; dismantled in 1999
PHWR	India (Kalpakkam) Canada Pakistan (KANUPP)	6,300 4,800	under commissioning under design under design
NHR	China		under design
HTGR	South Africa, France, The Netherlands		under consideration

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Hydrogen production using nuclear power

- High Temperature Electrolysis (up to ~ 1000ºC).
- Sulfur-based thermo-chemical cycles for water splitting:
  - Using Sulfur- Iodine cycle (needs about 900ºC)
  - Hybrid Sulfur cycle (i.e. Electrolysis and Thermo-Ch)
  - Lower temperature processes are under consideration
- Steam reforming of methane (600-800ºC)

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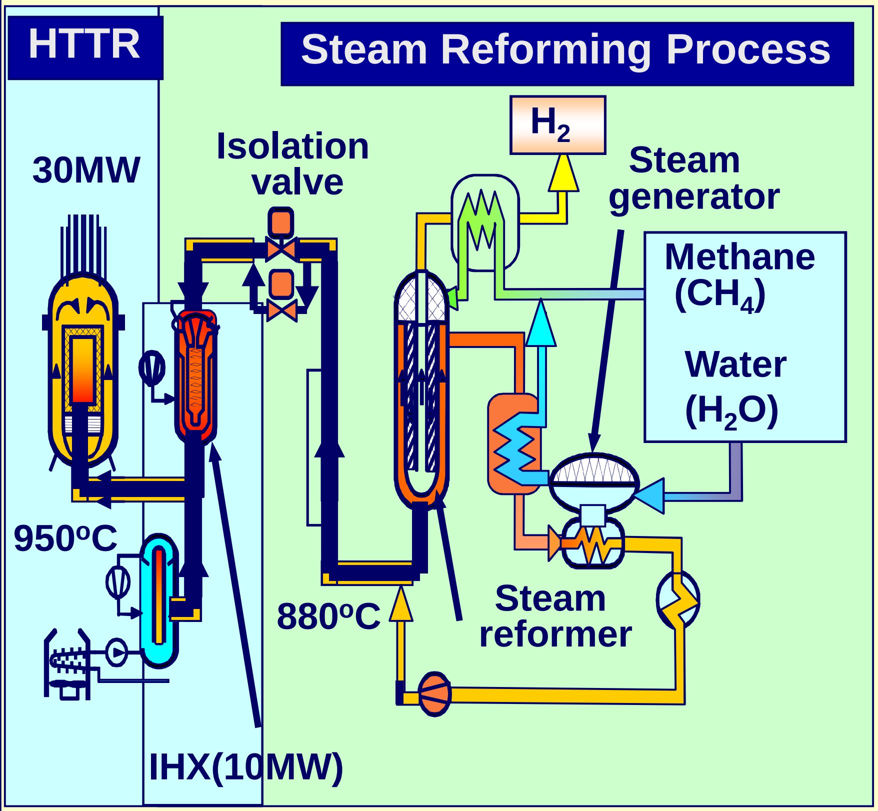
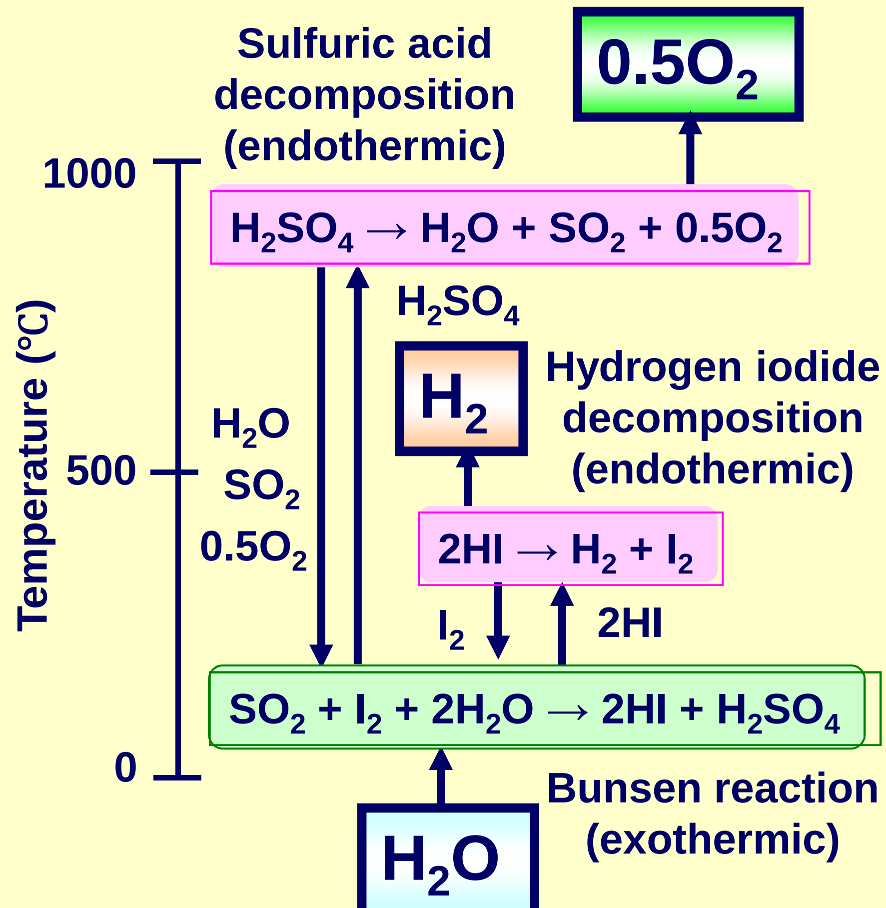
Hydrogen Production Systems

Steam Reforming Process



$$CH_4 + H_2O \rightarrow 3H_2 + CO$$

IS Process



ENERGY FOR TRANSPORTATION

- **Transportation**
  - **15 - 20% of the world's energy consumption**
  - **fastest growing energy sector**
- **If nuclear would power part of this sector, it could significantly impact global environmental sustainability**
- **Two examples:**
  - **Electricity**
    - **for plug-in hybrid electric vehicles (very near term)**
    - **For electric transportation systems (Trains; subways,…)**
  - **Hydrogen fuelled vehicles**

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Conclusions

- There are many designs to choose from
  - Not all are commercially available today
  - All have advantages and disadvantages
- Many of them have been:
  - Endorsed by User Requirements (EUR, URD, etc)
  - Certified by licensing authorities in several countries
  - Built and operated for many years in various countries… or
  - … In the process of being built

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Conclusions

- Considerations when choosing a design
  - Balance between technology maturity and innovation
  - Balance between constructability and operability
  - Advantages of “Owner Groups”
    - Operating Experience
    - Market for spare parts
    - Assurance of supplier support
  - Development of national capabilities
  - Electrical and non-electrical applications

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